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ANALYSIS OF TRENDS IN RESIDENTIAL ENERGY CONSUMPTION.(U)
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PREFACE

The General Accounting Office has produced a wide range of reports on many facets of the energy programs and policies that have come before the Congress, since energy was catapulted into prominence as a leading national concern in 1973. In this study, as in a previous report on trends in oil and gas supplies, 1/ we have sought to understand a sector of the Nation's energy system in detail, in order to be better prepared to deal with programs and policy issues that arise concerning that sector.

Our analysis has been aimed to focus on the most significant physical factors that drive residential energy use. In addition, we have explicitly examined how much uncertainty there is in a projection of future energy use, and where that uncertainty arises.

We based our analysis on historic residential fuel supply data compiled by the Energy Information Administration of the Department of Energy, population and housing data compiled by the Census Bureau, and analyses of past residential energy use carried out by leading research organizations. Assumptions about future trends in the key factors driving residential energy consumption were based on recent trends and a weighing of views expressed in the research literature.

The salient point which emerges from this analysis is that space heating in homes already built by 1977, our base year, is expected to consume the largest single share of residential energy through the balance of the century. Furthermore, the uncertainty about how large that segment of residential energy consumption will be provides the majority of the uncertainty in our overall projection. Taken together with our past and ongoing work on residential energy conservation programs and policies, this analysis leads us to expect that the improvement of energy efficiency in previously built homes will be the most important focus for energy policy in the residential sector in the coming years.

This study is being provided to committees and members of the Congress and others concerned with residential energy consumption and conservation. In addition, copies will be made

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1/U.S. General Accounting Office, "Analysis of Current Trends in U.S. Petroleum and Natural Gas Production," EMD-80-24, Dec. 7, 1979.

available to interested persons on request. Questions about this study can be directed to Donald Z. Forcier, Senior Group Director, or Richard Frankel, Energy Policy Group, on (202) 275-3563.

J. Dexter Peach
Director
Energy and Minerals Division

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STAFF STUDY BY THE U.S. GENERAL ACCOUNTING OFFICE

ANALYSIS OF TRENDS IN RESIDENTIAL ENERGY CONSUMPTION

D I G E S T

Net energy consumption in the residential sector is projected to achieve essentially zero growth in the latter part of the century, 1/ despite an approximately 40-percent increase in the number of households. This will be possible due to much more efficient residential use of energy. The projection shows a slowing increase in net consumption from 1977 to 1985, totalling about 7.4 percent, or less than 1 percent per year, and then a virtually constant level of consumption through the balance of the century. (See pp. 24 to 27.)

This projection sharply contrasts with the 1960s, which showed an annual growth rate of 3.6 percent. It appears more compatible with the 1970-77 period, which showed a total increase of only 2 percent, a result of a temporary 6.4 percent decrease in net consumption at the time of the Arab oil embargo. (See pp. 16 to 18.)

Gross residential energy requirements are projected to continue to increase over the period, 1/ although more slowly than in the past. The annual rate of growth should slow from 1.9 percent a year for 1977-1985 to only 0.7 percent a year in the 1990s. In contrast, gross consumption grew at 4.6 percent per year in the 1960s but slowed to 1.9 percent for 1970-77, again reflecting a discontinuity at the time of the Arab oil embargo. (See pp. 16 and 26 to 29.)

Gross consumption increases faster than net consumption because it includes the losses associated with electricity, and the projection shows a continuation of trends toward increased electrification of the residential sector. From

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1/Net energy is the energy purchased by the consumer. It differs from gross energy in that gross energy reflects the energy extracted from the ground. Gross energy includes electrical conversion, transmission, and distribution losses, while net energy does not.

a 21.6-percent share of net residential energy in 1977, electricity is projected to increase to about 31 percent in 1990 and 35 percent in 2000. (See pp. 26 to 29.)

Yet, despite this substantial reduction in the growth of energy use, a comparison of the projected energy consumption with a previous GAO study of trends in U.S. oil and gas production indicates the residential sector may still create pressure for additional oil imports throughout the 1980s. 1/ This is because the decline in U.S. oil and gas production in the 1980s is projected to be faster than the decline in consumption of oil and gas in the residential sector. Current trends indicate a possible requirement for additional imports of as much as 0.55 quads in the residential sector by 1990 over 1977--or about 270,000 barrels per day. (See pp. 42 to 43.)

Such an increase could be forestalled by any combination of

- --increased energy supplies from synthetic fuels, solar energy, and unconventional oil and gas;
- --residential energy efficiency improvements greater than those included in our assumptions;
- --greater electrification of the residential sector than is indicated by current trends, with a corresponding further expansion of electricity generation; or
- --changes in residential consumer life-styles which result in the use of lower levels of energy service.

None of these possibilities appears easy or certain, and all are likely to involve unanticipated delays and problems. Restraining or reducing energy imports in the 1980s is likely to require continued efforts to aid progress on all of these fronts.

1/U.S. General Accounting Office, "Analysis of Current Trends in U.S. Petroleum and Natural Gas Production," EMD-80-24, Dec. 7, 1979.

The study also indicates that the largest opportunity for future efficiency improvements in the residential sector is in homes that are already built.

Striking efficiency improvements already underway and expected in new residential construction, combined with demographic changes which will likely slow the rate of construction substantially over the balance of the century, indicate that only about 13 percent of residential energy use in the year 2000 will go to heat homes that are not yet built. However, even taking account of efficiency improvements, it will be nonheating energy uses, at 43 percent, and the heating of homes already built by 1977, at 44 percent, which it is estimated will use the major shares of residential energy in 2000.

Improvements by the construction and appliance manufacturing industries, already occurring under stimulation both from consumer concern about energy costs and from Government actions on labeling, goals, and possibly standards, will continue to upgrade the efficiency of energy use in new homes and in nonheating uses.

In contrast, improvements in the heating efficiency of existing homes will require actions by millions of consumers. The extent to which the private sector will respond to realize gains in heating efficiency in existing homes, and the effectiveness of any Federal initiatives directed at this target, are major uncertainties at this time.

Therefore, the study indicates that the improvement of heating efficiency in existing homes should be the focus of government policy attention in the residential sector, seeking to find both the most effective retrofitting measures to take, and the most effective institutional approaches to identify and deliver these measures. (See pp. 44 to 45.)

This study of energy use in the residential sector is one of a series of occasional analyses of energy supply and demand trends. A previous report was issued on the outlook for U.S. oil and gas production. An analysis of the transportation use sector is in process.

Contents

ABBREVIATIONS

BEPS	Building Energy Performance Standards
Btu	British Thermal Unit
DOE	Department of Energy
EIA	Energy Information Administration
FEDS	Federal Energy Data System
IEA	Institute for Energy Analysis (Oak Ridge)
NOAA	National Oceanic and Atmospheric Administration
OTA	Office of Technology Assessment
quad	Quadrillion (10^{15}) Btu's
RCS	Residential Conservation Service

CHAPTER 1

INTRODUCTION

The residential sector accounts for about 20 percent of U.S. energy use, providing power to the Nation's homes for heating, cooling, hot water heating, lighting, refrigeration, cooking, and the operation of other appliances. During the 1960s, residential energy purchases grew 3.55 percent per year, a rate which would have doubled residential energy use every two decades. However, growth in U.S. residential energy use began to slow in 1970. With the Arab oil embargo of 1973-74 and the ensuing energy price increases, there actually have been some decreases in total energy purchases. As a result, through 1977 total residential energy purchases had yet to return to their pre-embargo peak.

While energy prices will continue to affect residential energy use, consumer responses to these prices will be masked by nonprice factors such as availability of petroleum products and natural gas, regional migration patterns, and changes in U.S. demographic patterns. In short, not only is the United States undergoing great transitions in its energy prices, it is also undergoing great changes of other kinds which will subsequently affect U.S. energy use, even were prices to remain essentially unchanged.

OBJECTIVES AND SCOPE

Objectives

The purpose of this study is to analyze the underlying trends in U.S. residential energy use in terms of the physical factors which determine that use. The study estimates future consumption mainly on the basis of maintaining current levels of service, with some additional services included, to the extent that recent trends suggest they are likely to be demanded. It intentionally does not include the effects of consumers choosing, or being forced, to accept lower levels of energy services, whether spoken of as "life-style changes" or "freezing in the dark." To the extent that there are reductions in the levels of energy services used by consumers, actual residential energy consumption could be lower than estimated here. This possibility is discussed further in the final chapter. By understanding the trends in the physical factors, we were able to combine them to suggest what currently appears to be the most likely course of future U.S. residential energy use.

Scope

The estimate of trends in U.S. residential energy use presented in this study should not be regarded as a definitive forecast. Rather, it is an attempt to provide, based on

currently visible trends, a reasonable and prudent basis for national energy planning and comparative analyses of individual policies and programs affecting future residential energy use in the United States. In this study we did not examine or evaluate Federal Government programs in this field, though we recognize, of course, that these programs are active and could influence the trends we are examining. We hope that our description of the trends which are operating and presently foreseeable may assist in focusing discussion on those issues to which programs and policies should be addressed.

The following are major elements in this study:

--Identification of the basic factors which directly influence residential energy trends, for example, the number of households, the rate of retirement and construction of housing units, housing types, the geographical distribution of housing, and the efficiency with which energy is used for tasks.

--Analysis of the influence of these factors on past residential energy use.

--Analysis of the present and likely future trends in these factors.

--Projection of future trends in U.S. residential energy use resulting from the trends in these factors.

This approach differs from many other studies which, instead of making a single estimate of current trends, present a set of scenarios to indicate the effects of alternative trends, policies, or programs. Also, because we have not focused explicitly on energy prices, our projections will differ from econometric approaches, for which supply and demand are determined primarily by energy prices. Our approach is intended to describe the basic physical and technical factors which would underlie econometric descriptions.

Our analysis should provide a basis to assess

--other analyses of residential energy use,

--the effects of policy initiatives affecting U.S. energy use, and

--future trends in and issues affecting U.S. energy use.

METHODS

Because residential energy use data apportioned among particular end uses (i.e., heating, cooling, water heating, lighting, etc.) is very limited, we were compelled to make our assessment of the trends in residential energy use at an aggregate level. While ideally such an assessment should analyze residential energy use by analyzing the trends in each individual end use within the sector, the lack of adequate and consistent data indicates that such assessments would be based as much or more on the individual analyst's model of energy use as on actual measurements of that use.

As a result, our analysis assesses two major trends: the number of households and the energy use per household. Residential energy use will be the product of these two terms. Because of the importance of heating to residential energy use and its response to conservation actions, our assessment of energy use per household is broken down into heating and nonheating components.

We have treated energy use per household in terms of the energy purchased by that household. This is significantly different from most other analyses (with the exception of recent EIA work) which include electricity generation losses in sectoral energy use.

In general, residential energy use can be viewed from three different perspectives: (1) the total U.S. energy system requirements (gross energy), (2) the energy purchased by the residential consumer (net energy), and (3) the actual use the energy is put to in the residential sector (useable energy). Depending upon the perspective used, the apparent trends in residential energy use can differ significantly.

Gross energy

Gross energy is what the energy system must consume to provide the net energy the consumer purchases. It takes about 3.4 units of energy to produce and distribute one unit of electricity, for an efficiency of 29 percent. These losses are usually included in most analyses of residential energy use. On the other hand, the efficiencies for natural gas and petroleum products are about 90 percent and 82 percent respectively. 1/ These "losses," however, are almost never included in a discussion of gross energy use; they are usually assigned as energy consumption in the industrial and transportation sectors.

1/See Wen S. Chern, "Demand and Conservation of End-Use and Primary Energy in Residential and Commercial Sectors," *Energy Systems and Policy*, Vol. 2, No. 2, 1978, p. 281.

Net energy

Net energy is measured at the point of entry to the home. It does not include energy expended in the production or distribution of any forms purchased by the residential consumer. As such, it gives a better sense of the user's perception of the effects of energy conservation than does gross energy. A residential consumer thinks of energy conservation in terms of the electricity he can save in his house, not how many Btu's of fuel he can save in an electric generating plant.

Useable energy

This third measure of residential energy takes into account the relative efficiencies of the end uses of the energy. Electricity used in space heating is more efficient, measured at the point of use, than natural gas or oil space heating. Electricity used directly can convert one unit of electric energy into essentially one unit of heat energy (or even two or three units of heat, with a heat pump) whereas gas and oil are only about 50 to 60 percent efficient. 1/2/ That is, the fluid fuels convert only 1-2/3 or 2 units of energy into one unit of heat, with the "lost" energy mostly the heat going up the flue. A home that converted from oil or gas to electric heat would purchase less energy because of the efficiency of the electric form, even though the energy available for heat would be unchanged. On the other hand, from a gross energy perspective, the house would use more energy because of greater losses involved in electricity generation.

Comparison

Energy viewed from these three perspectives focuses on different policy avenues available to reduce energy use in the residential sector. If more efficient methods of electricity generation were developed, then gross residential energy use would be changed, but neither net nor useable energy. On the other hand, if the consumer lowered his thermostat then all

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1/See Wen S. Chern, "Demand and Conservation of End-Use and Primary Energy in Residential and Commercial Sectors," Energy Systems and Policy, Vol. 2, No. 2, 1978, p. 269.

2/The efficiency of oil and gas heating systems is a subject of some contention among analysts. One reviewer of a draft of this study noted that future values should be 70 to 80 percent, based on standards for new heating systems, while another reviewer said that actual values were only 33 to 50 percent, but appeared higher because other energy sources in homes provide a good deal of heat which is credited incorrectly to the heating system.

forms of energy would be reduced. Lastly, if the consumer installed a heat pump, which would increase his efficiency of electricity use, useable energy would be unchanged, but both gross and net energy would be reduced. Table 1 illustrates the historical trends in U.S. residential energy use measured according to these three perspectives.

Table 1

U.S. Residential Energy Use

	1960	1965	1970	1975	1977
	----------(trillion Btu's)----------				
Gross (note a)	8,800	10,658	13,761	14,828	15,652
Net	7,183	8,346	10,076	10,004	10,283
Useable (note b)	4,252	5,022	6,229	6,402	6,658

a/Calculated using ratio of electricity sales to energy consumption in the electricity sector.

b/Calculated based on net energy, using 55 percent efficiency for non-electric fuels and 100 percent for electricity.

Table 1 indicates the impact of the increasing electrification of the U.S. residential sector. Between 1970 and 1977 the amount of energy purchased by the U.S. residential sector has remained virtually constant, only growing 2 percent, compared to an increase of over 40 percent in the 1960s. Despite the almost constant level of energy purchases since 1970, the overall U.S. energy system increased its energy use for the residential sector almost 14 percent as a result of the losses associated with growing amounts of electricity generation. Finally the amount of useable energy has increased almost 7 percent since 1970 because electricity delivers more useable energy per purchased Btu than oil or gas. Thus, although U.S. residential consumers have barely increased their energy purchases since 1970, the level of useable energy has increased noticeably. However, the price for this increased level of useable energy is an even larger growth in the overall demand for energy placed on the U.S. energy system.

Placing these three perspectives on a per household basis illustrates the differences even more. Table 2 shows that, while the average U.S. household has reduced its energy purchases more than 13 percent between 1970 and 1977, it reduced its useable energy only 9.1 percent over that same interval, because of increasing electrification. The price of this, however, has been that the household demand on the U.S. energy system fell only 3.2 percent and, in fact, may have begun to grow again starting in 1975.

Table 2

U.S. Residential Energy Use per Household

	1960	1965	1970	1975	1977
	------(million Btu's per year)------				
Gross	167	185	217	207	210
Net	136	145	159	140	138
Useable	81	88	98	90	89

The gross method is clearly sensitive to the levels of electricity use, and electricity use per household has been rising through the sixties and seventies. Consequently, the gross method diverges from the other two indicators.

The gross method is a good measure of what the U.S. energy system requires to satisfy demand in the home, while the useable method is a closer approximation of the amount of energy service actually being used in the home. The net method of analysis is probably the easiest to understand because it deals with the quantities of energy people actually buy for their homes. Also, the net energy measure focuses most accurately on the premium fuels--natural gas and petroleum--about which our energy policy is most concerned. While these fuels are now used in significant amounts to generate electricity, their share of electricity generation is expected to decline, so policy concern in the future will most properly be guided by tracking net energy use. For these two reasons, our analysis of residential energy use will be based on net energy trends. Any treatment of gross or useable energy will be based on values derived from these net energy estimates.

SOURCES OF DATA

Ideally, to analyze trends in residential energy consumption, we would need a reasonably accurate time series of data disaggregated into separate end uses.

Two major studies done in the mid-1970s attempted to disaggregate 1970 residential energy consumption, 1/ but had to depend on numerous approximations and assumptions, for lack of detailed data.

1/Stephen H. Dole, "Energy Use and Conservation in the Residential Sector: A Regional Analysis," Rand Corporation, June 1975.
Project Independence Blueprint, Task Force Report, "Residential and Commercial Energy Use Patterns, 1970-1990, Vol. I," Arthur D. Little Co., Nov. 1974.

Survey work to assemble the kind of data which we would need has now begun, with the results of the first year's work recently released, 1/ but this data does not yet provide a time series from which we could examine trends.

Lacking consumption data which could support a disaggregated analysis, we have been forced to use supply data, showing the overall amounts of individual fuels delivered to the residential sector. Even this kind of data can vary depending on definitions of the consumption sectors. Utility industry data on the sales of fuels to classes of customers (residential, commercial, industrial) does not completely correspond to the respective sectors in an energy data system. More properly speaking, the utility classifications treat small, large, and very large users. While these approximately correspond to residential, commercial, and industrial sectors, they can result in mis-assignment of energy use to a particular sector, as in the case of a large apartment complex with a single meter which could be classified commercial or even industrial instead of residential.

The analysis contained in this study is based on energy data from the EIA/DOE Federal Energy Data System (FEDS) because it offers a self-consistent series of data for a sizeable time-span, from 1960 to 1977. 2/ In all comparisons which we made between our results and those of other studies, we made adjustments to correct for differences in absolute values for energy consumption between the FEDS and other data sets, should they occur. Additional data on heating fuel choices and on residential energy-using equipment were obtained from Census Bureau construction and housing reports, while population data and projections were obtained from other Census publications.

1/Energy Information Administration, "Residential Energy Consumption Survey: Consumption and Expenditures, April 1978 through March 1979," Department of Energy, Report DOE/EIA-0207/5, July 1980.

2/Energy Information Administration, "Federal Energy Data System (FEDS), Statistical Summary Update", Department of Energy, Report DOE/EIA-0192, July 1979.

CHAPTER 2

TRENDS IN THE NUMBER OF HOUSEHOLDS IN THE UNITED STATES

The trends in numbers of households and their geographic distribution will significantly affect trends in residential energy use. It is important to note that our analysis deals with trends for households, not housing units. This avoids counting vacant housing and extra (e.g., vacation) homes. Treating residential energy consumption on this basis stresses that it is people, not structures, which use energy. Also the residential sector, as usually defined, excludes group residences such as hospitals, dormitories, and military barracks that are usually included in the commercial (or governmental) energy consuming sectors. This chapter will describe the trends in household formation from a national and a geographical perspective.

NATIONAL HOUSEHOLD TRENDS

The number of households in the United States is increasing faster than the rate of population growth. This is because the number of households per adult population is also increasing. 1/ In 1950 there were 0.45 households per adult, by 1975 there were 0.55 households per adult, an increase of 22 percent. This is largely due to the increasing number of single-adult households resulting from

--a declining marriage rate in the younger groups,

--a growing number of widows who live alone (a woman's life expectancy now exceeds a man's by almost 8 years)

--a high divorce rate.

Assuming that these social trends continue, it is likely that the future growth of households will continue to exceed the growth in population. However, it appears unlikely that the rapid growth in headship (households per adult) experienced since 1950 will continue as strongly in the future. This is chiefly because

--the birth rate began dropping in the 1960s, so that the rate of increase of new potential household heads will begin to slow, and

--the rate of economic growth in the United States is expected to be slower than that experienced over the

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1/We are defining adult population as those 22 years of age or older.

period 1950 to 1973, which will slow the rate of single-adult household formation.

Our estimates for the trends in households through 2000 made use of the Census Bureau's Series II population projections 1/ and the 1975 Series B household projections. 2/ The Series B household projections are based on the observed trends in household formations from 1960 through 1974 and represent a "middle of the road" set of assumptions. The Census Bureau has recently updated its household projections based on the household formation rates from 1964 to 1978. 3/ These projections are significantly higher than the 1975 estimates, because they are dominated by the large number of single adult households formed in the mid-1970s.

It should be recognized that Census Bureau Series B household projections are not predictions. Rather, they are extrapolations, by a fixed mathematical formula, based entirely on data from a 15-year base period. For the reasons previously mentioned, we do not believe that the strong surge of single adult household formation in the mid-1970s, which dominates the 1979 projections, can continue through the end of the century as strongly as it did in the 1970s. Therefore, we have held with the 1975 projections as a basis for estimating future household formation rates.

The number of households can be projected in terms of an expected trend in the ratio of households per adult, as shown in table 3. Adult population projections in the table are all from Census sources already cited, as are ratios through 1990. For that year the ratio is approximately 0.58, and we have allowed it to grow somewhat more, to 0.59 in 2000. The rate of increase in number of households, however, is significantly slower than that experienced previously, because of the much slower growth in adult population which Census has projected for the 1990s compared to the present.

1/U.S. Bureau of the Census, "Projections of the Population of the United States: 1977 to 2050," Current Population Reports, Series P-25, No. 704, July 1977.

2/U.S. Bureau of the Census, "Projections of the Number of Households and Families: 1975 to 1990," Current Population Reports, Series, P-25, No. 607, August 1975.

3/U.S. Bureau of the Census, "Projections of the Number of Households and Families: 1979 to 1995," Current Population Reports, Series P-25, No. 805, May 1979.

Table 3

Adult Population and Household Projections

Year	Adult Population	Households	Households/Adult
	---------(millions)	----------	
1975 (actual)	130.314	71.5	0.55
1980	143.061	80.0	0.56
1985	155.145	87.8	0.57
1990	164.230	94.9	0.58
1995	171.362	100.0	0.58
2000	176.410	104.7	0.59

By 2000, households will have risen to 104.7 million, an increase of 46.4 percent over 1975. From 1980 on, however, the rate of increase in households will slow. From 1995 to 2000, the number of households added will be less than 60 percent of the increase projected from 1975 to 1980.

Since household formations occur almost exclusively in the adult population, most of the persons forming households between now and the end of the century have already been born. A sudden shift in the birth rate would not affect household formation until after the turn of the century. For this reason, we feel fairly confident that our national projection of 104.7 million households by 2000 is reasonable.

Table 4

Household Projections for the Year 2000

Study	Households (millions)
GAO	104.7
Department of Agriculture (note a)	100.9-103.5
Oak Ridge National Laboratory (ORNL) (note b)	106.5-108.0
Joint Center for Urban Studies (JCUS) (note c)	d/101.7

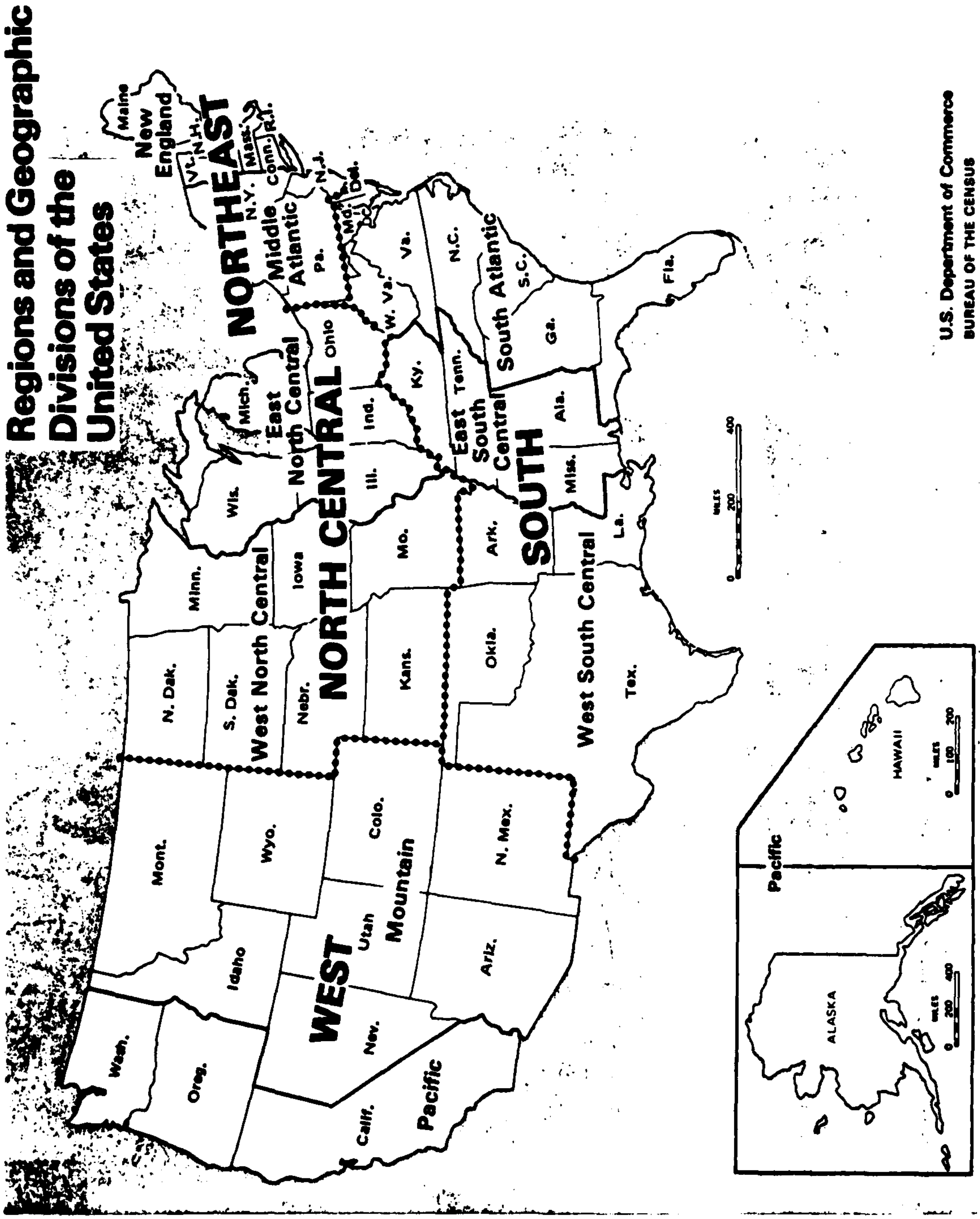
a/T. C. Marcin, "Outlook for Housing by Type of Unit and Region: 1978 to 2000", USDA, Forest Service Research Paper FPL 304, 1977.

b/E. Hirst and J. Carney, "The ORNL Engineering-Economic Model of Residential Energy Use," ORNL-CON-24, July 1978.

c/J. Pitkin and G. Masnick, "Analysis and Projection of Housing Consumption by Birth Cohorts: 1978-2000," MIT-Harvard Joint Center for Urban Studies, August 1979.

d/Mid-Range estimate of JCUS study.

Figure 1



Regions and Geographic Divisions of the United States
NORTHEAST
New England
Middle Atlantic
NORTH CENTRAL
East North Central
West North Central
SOUTH
South Atlantic
East South Central
West South Central
WEST
Mountain
Pacific
Maine
N.H.
Vt.
Mass.
Conn.
R.I.
N.Y.
N.J.
Pa.
Del.
Md.
Ohio
Mich.
Ind.
Ill.
Wis.
Minn.
Iowa
Mo.
N. Dak.
S. Dak.
Nebr.
Kans.
W. Va.
Va.
N.C.
S.C.
Ga.
Fla.
Ky.
Tenn.
Ala.
Miss.
Ark.
La.
Okla.
Tex.
Mont.
Wyo.
Colo.
N. Mex.
Idaho
Utah
Ariz.
Nev.
Wash.
Oreg.
Calif.
ALASKA
HAWAII
U.S. Department of Commerce
BUREAU OF THE CENSUS

A comparison of our estimates of households in the United States with those of other studies which we identified in the course of this analysis is shown in table 4. Table 4 shows that our estimate is approximately at the mid-point of the range of the other studies. The high estimates of the Oak Ridge National Laboratory study assume economic growth rates approaching those of the 1960s, which are regarded as not likely to occur. On the other hand, the low estimates amount to a halt to the increase in the ratio of households per adult. This implies an economic growth rate significantly slower than that of the 1970s, which is also regarded as unlikely.

GEOGRAPHICAL HOUSEHOLD TRENDS

Historical data on the geographic distribution of households is available from the Census Bureau through 1977. Figure 1 shows a map of Census divisions and regions in the U.S. Although Census does not project the number of households on a divisional basis, it does project population by States. These population figures can be used to project the geographic distribution of households.

A recent Census Bureau report presents population projections by State through the year 2000 in three different migration patterns: Series II-A, based on the 1965-1975 pattern; Series II-B based on the 1970-75 pattern; and Series II-C, which assumes no net migration since 1975 and is presented for information only. 1/ A comparison of these trends, aggregated by regions, is shown in table 5.

Table 5
Percentage of the U.S. Population Contained in Regions
1970 to 2000

	Estimates		Projections for 2000		
Region	1970	1975	Series II-A	Series II-B	Series II-C
Northeast	24.2	23.2	21.1	20.5	23.0
North Central	27.8	27.1	25.3	24.4	26.8
South	30.9	31.9	34.0	35.6	31.5
West	17.1	17.8	19.6	19.6	18.7

In general, the use of the 1970-75 pattern tends to widen the differences among the regions, with the Northeast and North Central Regions losing more of their population to the South. Both patterns allow the West to grow at the same rate. We have

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1/U.S. Bureau of the Census, "Illustrative Projections of State Populations: 1975 to 2000 (Advance Report)," Current Population Rcrorts, Series P-25, No. 735, Oct. 1978.

chosen the migration projection in Series II-A, because it is derived from a longer base period. Using the 1970-75 trend alone would, we believe, carry one single migration pattern over a longer period than such patterns have tended to persist in the past.

Projecting households from divisional population figures requires that certain national patterns be assumed to hold true in each division, even though we realize that variations exist. Assumptions include the following:

--Adults make up the same percentage of the population in each division as they do for the Nation for each year of the projection period. (For example, if in 1980, 67 percent of the people in the U.S. are age 22 or over, then 67 percent of the people in New England are 22 or over, 67 percent of the people in the Middle Atlantic are 22 or over, etc.)

--The pattern of household formation in proportion to the adult population is the same for each division as it is on a national basis.

When projections made using these assumptions were retrofitted to the 1970 and 1972-76 time period and the results compared to the observed number of households in each division, only the Pacific division ever differed by more than 3.1 percent. Correction factors were then developed and applied to the divisional household projections. (See app. I.) The resulting distribution of households is shown in table 6.

Table 6

Distribution of Households by Geographic Division
(millions)

Division		1977	Percent of total, 1977	1980	1990	2000	Percent of total, 2000
I	New England	4.174	5.60	4.5	5.4	5.8	5.54
II	Mid-Atlantic	12.952	17.36	13.8	15.5	16.5	15.76
III	East North Central	13.896	18.63	14.8	17.2	18.6	17.76
IV	West North Central	5.885	7.89	6.2	7.1	7.7	7.35
V	South Atlantic	11.748	15.75	12.9	15.9	18.1	17.29
VI	East South Central	4.576	6.14	4.9	5.7	6.2	5.92
VII	West South Central	7.311	9.80	7.8	9.5	10.7	10.22
VIII	Mountain	3.382	4.53	3.7	4.6	5.2	4.97
XI	Pacific	10.664	14.30	11.4	14.0	15.9	15.19
	Total	74.588	100.00	80.0	94.9	104.7	100.00

SUMMARY

Households will increase from 74.6 million in 1977 to approximately 104.7 million by 2000. The increase will be due largely to an increase in population, with some continuation of a trend toward fewer adults per household. However, by the mid-1980s household additions will begin to slow and by the 1990s slow even more.

The expected average annual net household additions from 1977 to 2000 are shown in table 7, which demonstrates that the rate of net household additions is expected to slow significantly in the next two decades. By the 1990s, the average increase in households will not even reach 1 million, down 45 percent from the period 1977 to 1980. This would imply that the rate of new housing construction will slow significantly, unless the rate of housing unit retirements increases substantially, an unlikely prospect unless the economy is extremely healthy. With a slower rate of new construction, the impact of improvements in new housing construction on residential energy use would be significantly reduced compared to the impact expected if construction continued at the pace of nearly 2 million units per year seen through much of the 1970s.

Table 7

Average Annual Net Household Additions

	Households (millions)	Annual growth (percent)
1977-1980	1.80	2.4
1980-1990	1.49	1.7
1990-2000	0.98	1.0

CHAPTER 3

HISTORICAL PATTERN OF U.S. RESIDENTIAL ENERGY USE

Total energy purchases for the Nation's homes (net energy) increased by about 43 percent from 1960 to 1977. This growth, however, was not uniform over time, nor was it evenly distributed across the Nation or uniform among the various forms of energy used in homes. In the following sections we discuss overall national growth in energy use, geographic difference in growth trends, and national and local differences in fuel use patterns.

NATIONAL TRENDS

In the 1960s, as shown in figure 2, total U.S. residential energy consumption grew at an accelerating rate. The average growth in total net energy consumption was 3.55 percent per year from 1960 to 1969, but the rate went up to 4.18 percent for the 1964-69 interval. After 1969, however, still before the Arab oil embargo, net residential energy consumption growth slowed to only 2.35 percent per year from 1969-72. Total net residential consumption then actually dropped starting in the embargo year, 1973, and as of 1977 had still not returned to the pre-embargo peak level of 1972.

Figure 2 also shows the course of gross residential energy consumption, which includes conversion losses in the generation of electricity used in the residential sector. (Gross energy used for electricity was calculated from the ratio of energy content in electricity sold to the energy content assigned to the fuel used to generate electricity--a ratio of 0.2907 was used throughout the period.) The growth rates of gross residential consumption are all greater than those for net consumption: 4.61 percent per year from 1960-69, 3.81 percent annually from 1969 to 1972, and 1.2 percent annually for the 1972-77 period when net consumption actually fell slightly.

A better way to understand these changes can be seen in the trends of net energy use per household, shown in figure 3. The rapid growth of total residential energy use up to 1969 can be seen to be, in substantial part, a result of the growth of energy use per household. From 1969 to 1972, however, energy use per household essentially stayed constant; thus the lower growth in total residential energy use for that period was solely due to growth in the number of households.

Net energy use per household in 1977 had fallen 13.3 percent from its 1970 peak. More than four-fifths of this decline occurred in the two embargo years, 1973 and 1974. Since 1974, there has been a smaller somewhat erratic decrease. In 1976 energy use per household grew nearly 2 percent, but this appears largely due to the coldest winter in almost a century. In 19'7,

Figure 2

Total Residential Energy Use

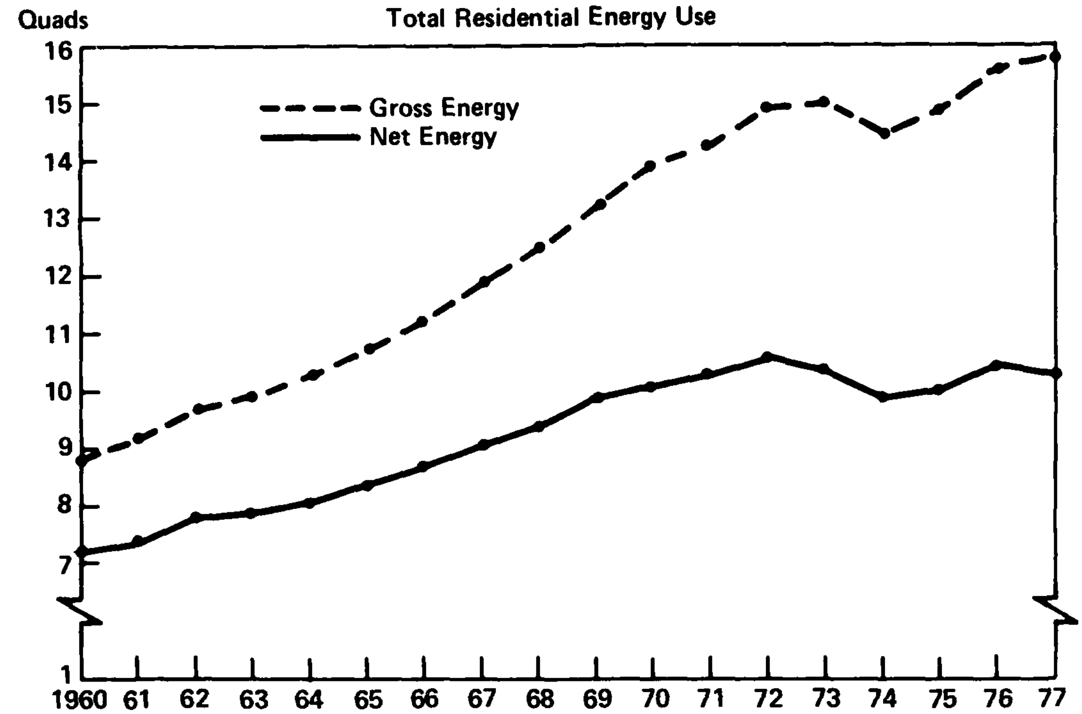
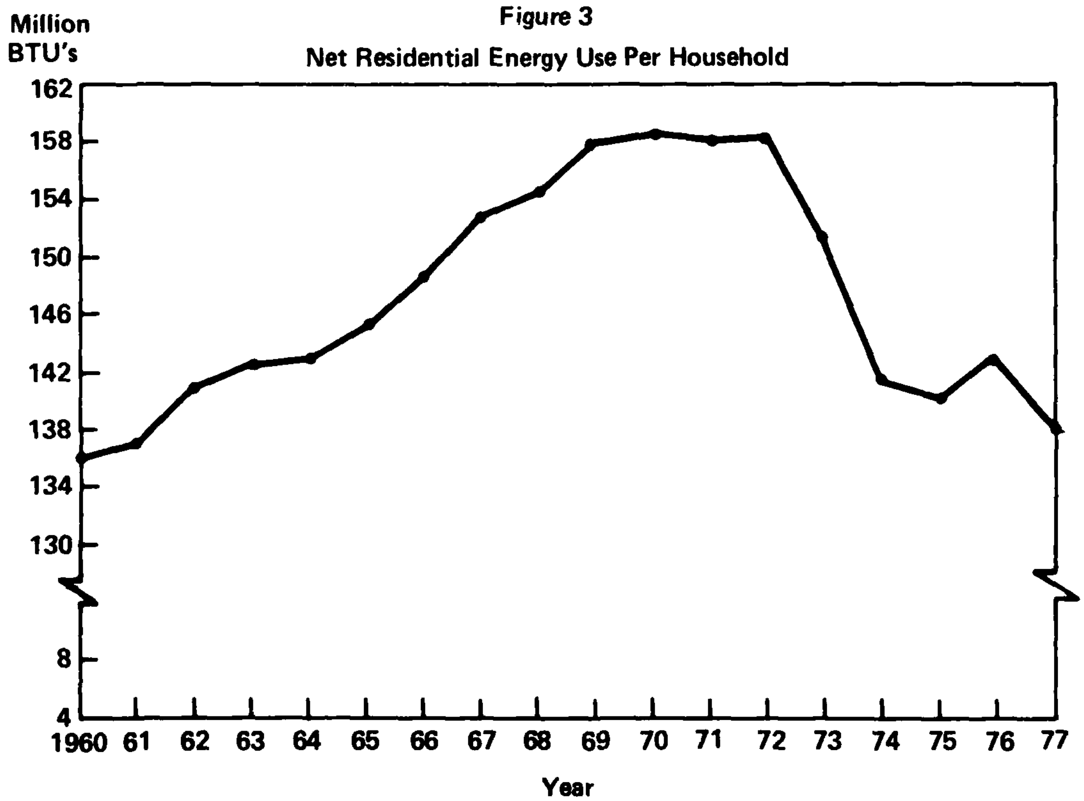


Figure 3

Net Residential Energy Use Per Household



the winter was also colder than average; nevertheless, net energy use per household declined 3.2 percent, its best improvement since the 1973-74 period. By 1977, the average U.S. household only used 1.5 percent more energy than it did in 1960.

GEOGRAPHICAL TRENDS

This slowing of energy consumption has been mostly a result of significant declines in residential energy use per household in the 1970s. Every Census division showed lower consumption per household in 1977 than in 1970. Indeed, in two cases--the South Atlantic and the New England divisions--1977 energy use per household was actually 7 and 9 percent below 1960 levels, respectively. Even in the East and West South Central divisions, which had energy use levels per household in 1977 that were respectively 25 and 29 percent larger than in 1960, the 1977 levels were still 12 and 7 percent below what they had been in 1970. Net energy use per household has remained higher in the North, and lower in the South and West. The differences, on the order of 50 to 100 percent, appear mainly attributable to the greater heating loads in the Northern States.

Since 1960 a noticeable shift of population has occurred from colder to warmer areas of the Nation. To assess the impact of this population shift on residential energy use, we compared the actual residential energy use in 1970 and 1977 to that which would have occurred had there been no net internal migration over the period from 1960 to 1977. The comparison showed that the net effect of migration over this period was to reduce 1970 net residential energy consumption by 0.9 percent from what it would have been had there been no net migration since 1960. By 1977, actual net residential energy use was 2.2 percent lower than it would have been had 1960 population distributions persisted with the same levels of energy use per household as were actually observed in the 1970s. While these effects of migration are not negligible, they are much smaller than the impacts of overall growth in numbers of households, which was by itself responsible for a 20-percent increase in total residential consumption between 1960 and 1970.

FUEL USE PATTERNS

Regional population shifts have only had relatively small effects on total U.S. residential energy use. However, the different Census divisions have distinctly different fuel use patterns. In 1977 these ranged from 9 to 61 percent for oil, 14 to 38 percent for electricity, and 25 to 67 percent for gas. Thus, population shifts could significantly affect the mix of fuel used nationally, even if there were little effect on total energy use.

Nationally, there has been a shift in the kinds of fuels used in the residential sector. The main shifts have been in the use of petroleum products and electricity. Petroleum use

has dropped from a 31.6-percent share of residential energy use in 1960 to 23.0 percent in 1977. In contrast, electricity use over the same period grew from 9.3 percent of the total energy used in 1960 to 21.6 percent in 1977. Natural gas use has also grown over the years. Almost 4 percent more of total residential energy needs were met with natural gas in 1977 than in 1960.

In part, this can be associated with regional migration patterns in the United States. Without migration, the Nation would have continued to use more oil, slightly more natural gas, and slightly less electricity. The change in 1975 would be on the order of 4.5 percent more oil use, 1.8 percent more natural gas use and a drop of less than a percent in electricity use. The effects seen are to be expected because, without migration, the population would be held in regions which have higher oil use (percentage of the market share), and lower electricity use.

SUMMARY

Rapid residential energy consumption growth in the United States during the 1960s was the result of a combination of continuing increases in energy use per household (figure 3) and high rates of household formation. However, by 1970, net energy use per household stopped growing, leaving growth in residential energy use to be driven solely by increases in the number of households. Because the growth in household formation is expected to slow, it is reasonable to expect that the growth in residential energy use in the coming decades would have slowed accordingly, even without the shocks to the energy system of the middle and late 1970s.

Regional migrations had relatively little effect on overall net energy use patterns, however they had somewhat larger effects on fuel use patterns, particularly petroleum products.

CHAPTER 4

FUTURE TRENDS IN RESIDENTIAL

ENERGY CONSUMPTION

The purpose of this chapter is to (1) estimate what we currently judge to be the most likely course of residential energy use over the balance of this century and (2) indicate the extent of uncertainty in that estimate, and the sources of the uncertainty.

This estimate will be based on meeting anticipated demand (taking account of increasing numbers of households, and the efficiency improvements that we judge to be achievable over the period) without any reductions in levels of service. Such reductions, which are not easily estimated, and about which there is a good deal of disagreement among analysts, could cover a wide range of events. The mildest might be "demand management" steps such as time-of-day pricing or automatic centrally controlled cutoffs of selected appliances in peak hours. Other reductions in levels of service could range from further lowering in heating and cooling levels (by voluntary or mandated thermostat resetting) to the most overt kinds of "doing without," including formal allocation actions, scheduled brown-outs/blackouts, or unanticipated shortages or blackouts, or they could simply result from consumer choices to accept lower levels of energy services, in order to spend resources on other types of goods and services.

Since our aim is to estimate the level of energy consumption, rather than to examine the very complex question of how that consumption level will be determined, we will not explicitly treat the economic, regulatory, research, information dissemination, or other activities which will influence that consumption level. 1/ Econometric analysis, in particular, may be used to attempt to project future consumption and the way it can be affected by economic and other factors. In a sense, our treatment should be regarded as an examination of the physical changes which would underlie the results that an econometric analysis might project, with levels of service kept unchanged. Specifically, this chapter will

--discuss the expected changes in the underlying factors used to analyze the trends in residential energy use,

--present the trends in residential energy consumption through the end of the century resulting from the changes in these factors,

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1/We have reported on Government programs in these areas in "Residential Energy Conservation Outreach Activities--A New Federal Approach Needed" (EMD-81-8, Feb. 11, 1981) and earlier reports cited in that one.

--analyze the uncertainties in the trends, and

--compare the results with those of other studies.

TRENDS IN RESIDENTIAL ENERGY USE FACTORS

Because there are substantial disagreements among reputable studies even on the historical net energy consumption in the residential sector, and also because of substantial unexplainable disagreements between attempts to assign energy consumption to specific end uses (See app. II.), we believe that a reliable and accurate detailed description of residential consumption is beyond attainment at this time. Any such description would consist of a few bits of data floating in a sea of assumptions. We have, therefore, projected residential energy consumption in terms of simplified, aggregated factors. Briefly summarized, the projection is built up from the trends in energy use per household separated only into two parts--heating and other uses. Trends in heating energy use are treated separately in each Census division for two classes of housing units: those existing in 1977 and those built after 1977. The relative numbers of units in the two classes are determined for each future year by assuming that a constant number of the 1977 units are retired in each year, and that new units are added to house the remainder of the total number of households expected in that year. Combined with a short list of assumptions that represent our current judgment of the likely course of evolution in these three factors, this gives us a basis to project the trends in residential energy consumption.

We believe such a simple description, because it focuses on the physical factors governing residential energy use, will provide the reader an ability to readily understand the future trends in residential energy use. Also, because the effects of changes in those trends will be directly visible, readers will be able to track the projected trends against actual experience and adjust the projections if trends in the underlying factors change. A detailed description of the calculation and the data sources used to construct it is given in appendix II.

Heating energy trends

Heating energy use per household in existing structures is assumed to decrease over time, with the rate of decrease accelerating through 1990 and slowing thereafter. The acceleration expresses our expectation that insulation and other retrofitting of the existing housing stock will accelerate in this decade, as more and more occupants and owners come to recognize its value, and the industry which does the work or provides the materials grows, learns better skills, and develops better materials and equipment. The slowing of improvement in the 1990s expresses the expectation that diminishing returns will come in later years, after the easiest, most cost-effective retrofits are completed in earlier stages.

The assumed improvement in existing residences totals to a 19.4-percent reduction in average net heating energy consumption between 1977 and 2000. Combined with the reduction of energy use per household between 1970 and 1977, which is estimated in appendix II at 17 percent of 1970 heating energy, the total is equivalent to an overall reduction of about 33 percent in heating energy consumption per previously existing home between 1970 and 2000. For comparison, early post-embargo views 1/ were that the maximum improvement achievable in existing structures was a 17- to 29-percent reduction from 1970 consumption. On the other hand, our assumed level of improvement is well below the most optimistic saving estimates offered recently in studies of existing residences, which go as high as 50 percent of 1975 consumption. 2/

Heating energy use per household in residential structures built after 1977 is assumed to diminish greatly over time, down to levels in the 1990s, and beyond, which amount to only about one-fourth of the average for present units. This dramatic reduction in energy use for new units results from our assuming the attainment of levels of heating energy efficiency comparable to those included in the Building Energy Performance Standards (BEPS) which were proposed in 1979 by DOE. The BEPS proposal indicated that meeting the standards would not require use of exotic new technologies, but only good workmanship and care in applying existing approaches and methods to optimum levels which would minimize the total of construction and energy costs.

While the BEPS were proposed to be in effect within 2 years, we do not believe that actual heating efficiency of new houses will reach the BEPS levels so quickly. Effective attainment of these efficiencies will require a consistently high degree of quality control on the part of the Nation's diverse and fragmented housing construction industry, as well as increased attention on the part of the occupant of the housing unit to the heat integrity of the unit. As a result, we have taken a more gradual approach in applying the BEPS levels as a description of the actual performance of new housing. In our treatment, new housing units introduced over the 1977-90 interval gradually improve from 1977 levels of heating energy use, and actually perform at the BEPS levels only in 1990 and beyond. This relatively conservative course is not meant to bear on the issue, currently the subject of some controversy, of whether to promulgate the BEPS standards in the near future. It only means that we anticipate it will

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1/Project Independence Blueprint, Task Force Report, "Residential and Commercial Energy Use Patterns, 1970-1990," Vol. I. Arthur D. Little, Co., Nov. 1974.

2/M. Ross and R. H. Williams, "Drilling for Oil and Gas in our Buildings," Report PU/CEES 87, Princeton University Center for Energy and Environmental Studies, July 1979.

take some additional years before actual as opposed to design heating energy consumption by new residences can be expected to be brought down to the levels that are estimated in the proposed standards.

Trends in non-heating energy use

Non-heating uses currently account for about one-third of the average household's energy use. Attempts to quantitatively break down nonheating uses into particular services (water heating, air conditioning, cooking, food storage, lighting, etc.) are inconsistent and based on very sketchy data. In the major studies which we reviewed, such attempts resulted in unattributable balances in some parts of the country which approximated one-third of the total nonheating use. In addition there were significant regional variations of nonheating energy use in these studies which could not be explained by air conditioning, the only nonheating use which would be expected to show strong regional variation. Therefore, while we recognize that an aggregate description of nonheating uses is a rough approximation, we have chosen to treat all non-heating uses as one sum, because we do not regard more detailed treatments as supportable by available data.

There are two major trends currently acting which will work to drive nonheating energy use in opposite directions. One of these is a decrease in energy use per unit for most residential energy-using equipment. This is already occurring under stimulus from growing consumer concern and appliance labeling and appliance efficiency goals, and is likely to continue through the balance of the projection period, as more efficient equipment progressively replaces units currently in place, and new units continue to be designed with greater efficiency than present ones.

At the same time, a sharp growth is still underway in the number of air conditioners in place, increasingly represented by central air conditioning in new residences. This trend presently appears likely to continue through the balance of this century before it reaches saturation, as shown in appendix II. With air conditioning net energy use per household possibly amounting to as much as 10 million to 20 million Btu's per year (about 3000 to 6000 kilowatt hours) in the warmest parts of the country, this would tend to raise the average nonheating energy use significantly. Furthermore, other increases in the numbers of energy consuming devices (dishwashers, clothes dryers, and other uses that may develop over the next two decades) will also tend to increase nonheating energy use in residences, thus counteracting the reductions which will be occurring in energy use due to improved efficiencies of appliances.

As a result of these two counteracting trends, for neither of which we can yet make precise quantitative estimates, we assume that the nonheating energy use per household will remain essentially constant through the end of the century.

TRENDS IN RESIDENTIAL ENERGY USE

In 1977, the average U.S. household's net energy consumption was 138 million Btu's. This was more than 13 percent below the 1970 peak and the lowest consumption per household since 1961. The speed with which most of this decrease occurred, in 1973 and 1974, leads us to believe that this reduction was largely due to behavior changes (i.e., lowered temperatures) rather than efficiency improvements of the kind expected in the future.

National trends

We estimate that the decline in energy use per household will continue, but at a slowing rate relative to that experienced from 1973 to 1977. By the end of the century, net energy consumption will have declined about 22 percent below 1977 levels, to 107 million Btu's per household. Since our analysis has assumed no net change in the nonheating uses of energy per household, this decrease is entirely attributed to a reduction of energy used for heating. The projected average net energy consumption for heating declines from 92.2 million Btu's per household in 1977 to 61.3 million Btu's by the end of the century, an overall average reduction of 33.5 percent.

This reduction is the combined result of improvements in the remaining pre-1977 units, which results in a 19.4-percent decrease in their heating energy use per household, and much more dramatic decreases in heating energy consumption per unit in the new structures. The average net heating energy use projected for all new structures added between 1977 and 2000 is 37.3 million Btu's, a reduction of almost 60 percent from the average estimated for 1977. The average nationally for those built in the latter part of the period, performing at BEPS levels, is 23.2 million Btu's per household, fully 75 percent down from the 1977 national average. The resulting trend in net energy consumption in the residential sector is shown in table 8.

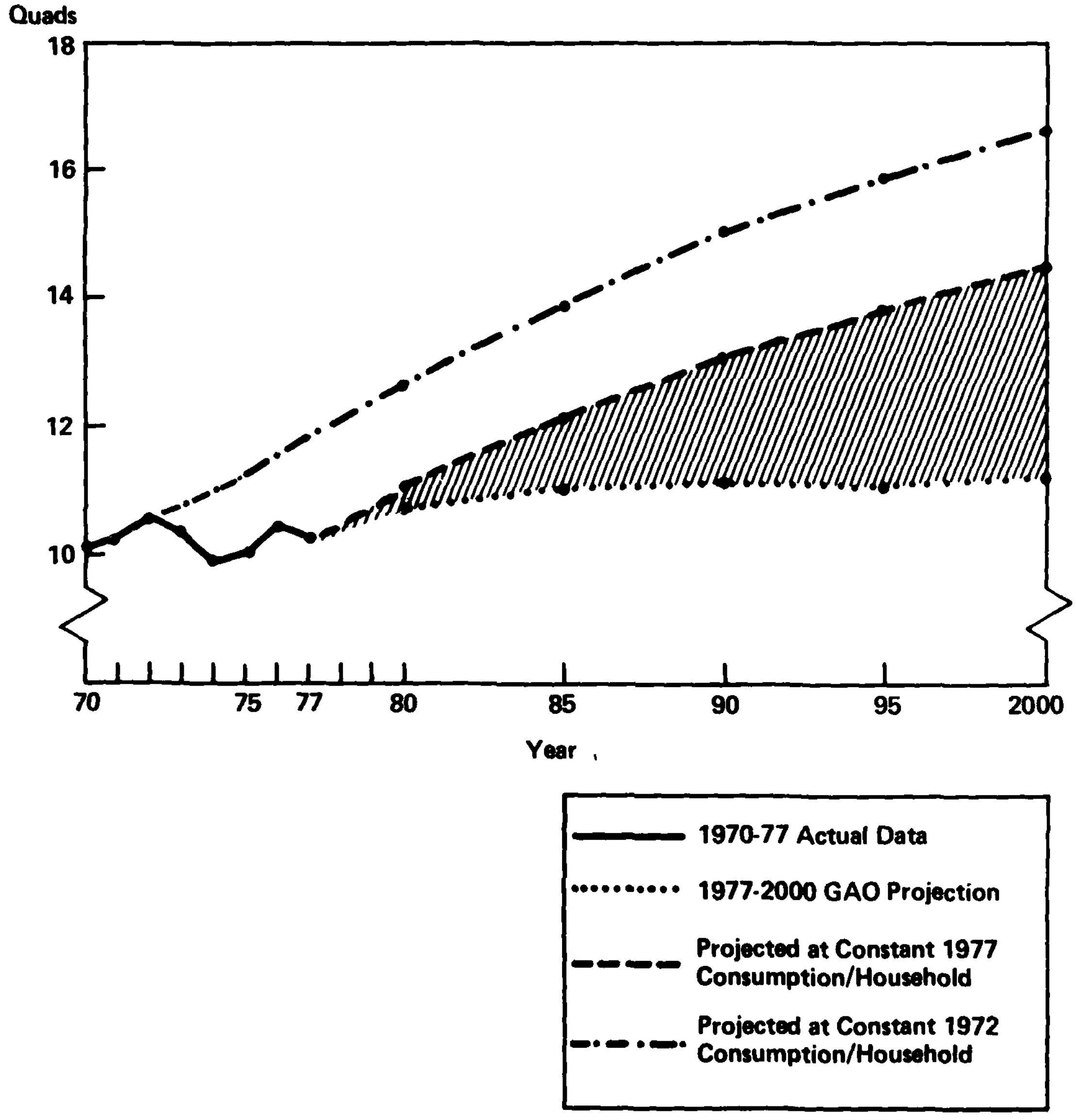
Table 8
Projected Net Residential Energy Use, 1977-2000

	Energy/household (millions of Btu's)	Households (millions)	Energy/Year (quads)
1977 (actual)	137.9	74.6	10.283
1980	133.9	80.0	10.711
1985	125.8	87.8	11.046
1990	117.0	94.9	11.099
1995	110.9	100.0	11.085
2000	107.0	104.7	11.199

Table 8 shows that, although the number of households should increase by 40 percent over the 1977-2000 period, total residential net energy consumption will increase only slowly through 1985, and

FIGURE 4

Total Net Residential Energy Consumption 1970-2000



then remain essentially constant through 2000. Over the entire 23-year period, net residential energy consumption will increase only 9 percent, an average of less than 0.4 percent a year. This projection represents a significant break with pre-embargo behavior, which indicated that residential energy use would have grown at least in step with the growth of households.

Figure 4 shows the level of consumption we have projected, plus two higher levels which would occur if energy use per household were to remain constant at 1977 levels (middle curve) or at 1972 levels (top curve). The difference between the lower and middle curves shows that, without the post-1977 efficiency improvements assumed in this study, total net residential consumption by 2000 would be projected some 29 percent higher than we have estimated, over 14.4 quads rather than 11.2 quads.

A breakdown of projected residential energy use into heating and nonheating parts in existing and new residences is charted in figure 5. It shows that projected net residential energy use at the end of this century is still expected to occur mostly (71 percent) in residences that existed in 1977, with over three-fifths of that, some 44 percent of total consumption, going to heat the older structures. The figure also makes clear that the anticipated improvement of thermal efficiency will significantly lower the proportion of total residential energy going to space heat, from an estimated 67 percent in 1977 to about 57 percent in 2000. It is striking that, only using what we regard as attainable levels of efficiency improvements, we project that 104.7 million residences, 30 million more than existed in 1977, will be able to be heated with slightly less total energy than was used in 1977.

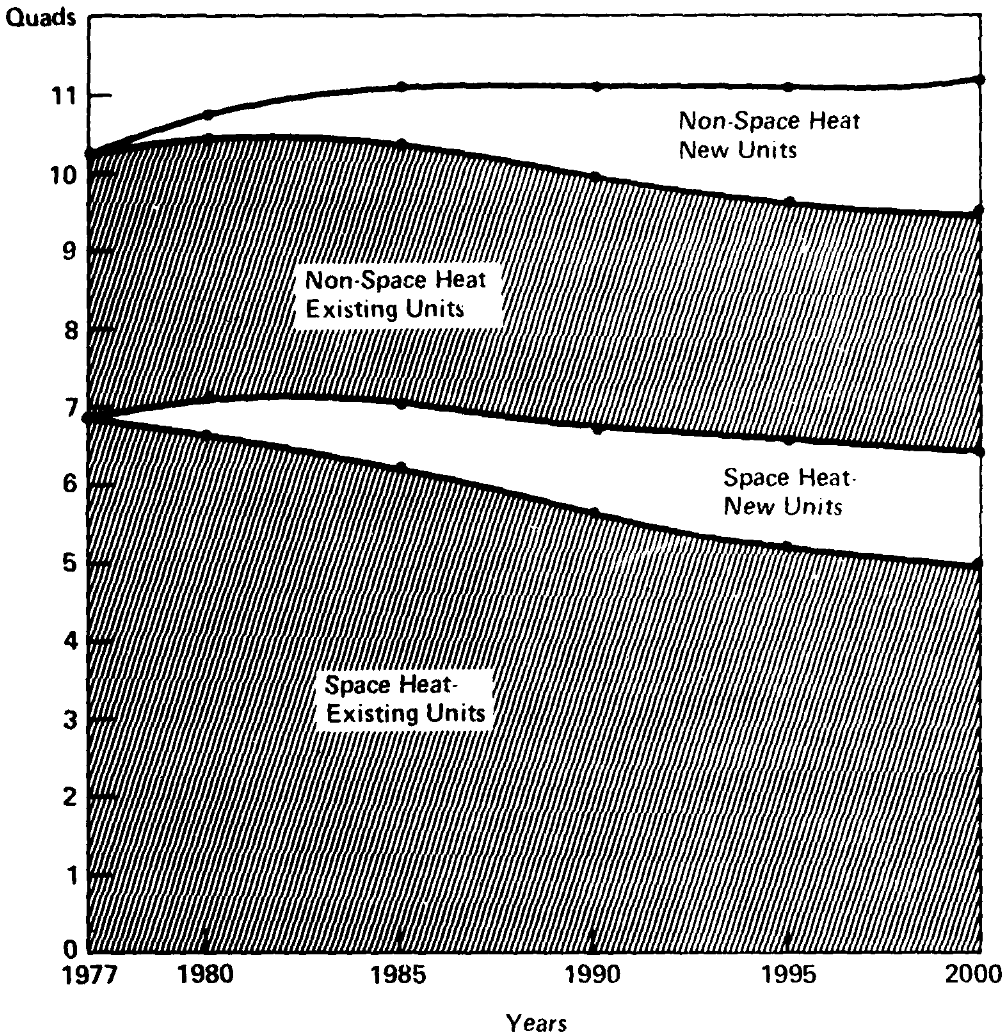
Consumption by fuel type

The U.S. residential sector has become increasingly dependent on electricity. Although total residential net energy use only grew about 2 percent over the period 1970 to 1977, electricity consumption in the sector grew 46 percent. As a result, electricity accounted for 21.6 percent of total residential net energy consumption in 1977, up significantly from a 15-percent share in 1970. Electricity use in the residential sector still appears likely to continue to grow, even though growth in overall residential net energy could virtually disappear by the mid-1980s.

This increasing electrification can be seen most graphically in home heating. As of 1977, 14.8 percent of occupied housing units were heated by electricity, up from 7.7 percent in 1970. Over the 1970-77 period, 52 percent of the additions to the housing stock were electrically heated. Similarly, between 1970 and 1977, the proportion of households with central air conditioning rose from less than 11 percent to over 22 percent, and those with room

Figure 5

Projected Breakdown of Net Residential Energy Consumption -- 1977-2000



units rose from 25 to 29 percent. 1/ Finally, the most recent construction report shows that over 56 percent of housing units built in 1979 had electric heat, and about 67 percent had central air conditioning. 2/

In projecting future residential energy consumption, we have attempted to account separately for electric and non-electric uses, as explained in appendix II. For this purpose, lacking any strong reason to change from present fuel choices, we generally assigned new units to the two categories at the rates observed in 1978. 3/ This resulted in a continuation of the trend toward greater electrification in the residential sector, and a projected rate of growth of electricity use which significantly exceeded the overall growth rate of residential energy consumption. The resulting fuel uses are shown in table 9.

Table 9

U.S. Residential Energy Fuel Use Trends

(quads)

Year	Electricity	Other fuels	Net	Gross
1977 (actual)	2.226	8.057	10.283	15.714
1980	2.564	8.147	10.711	16.967
1985	2.983	8.063	11.046	18.324
1990	3.393	7.706	11.099	19.378
1995	3.655	7.431	11.086	20.004
2000	3.912	7.287	11.199	20.744

1/U.S. Bureau of the Census, "General Housing Characteristics for the United States and Regions: 1977, Annual Housing Survey: 1977, Part A", Current Housing Reports, Series H-150-77, Sept. 1979.
Electrification continued strongly through 1978 also. Of occupied units 15.9 percent were electrically heated, 24 percent had central air conditioning, and 29.5 percent had room units, according to the 1978 Annual Housing Survey.

2/U.S. Bureau of the Census, "Characteristics of New Housing: 1979," Construction Reports, Series C25-79-13, Aug. 1980.

3/U.S. Bureau of the Census, "Characteristics of New Housing: 1978," Construction Reports, Series C25-78-13, Sept. 1979.
Construction in 1979 showed no significant evidence of a slowing of the trend toward electrification in heating, even though it did show gas heating was starting to increase, after its lower rate due to hookup moratoria in the mid-1970s. See: U.S. Bureau of the Census, "Characteristics of New Housing: 1979," Construction Reports, Series C25-79-13, Aug. 1980.

The projected annual growth rate of electricity consumption is 4.83 percent from 1977 to 1980. It shows a drop to 2.84 percent for the 1980s, and half that level, 1.43 percent, for the 1990s. The overall increase in electricity consumption in the residential sector is projected at 76 percent from 1977 to 2000, for an average annual growth rate of 2.48 percent. As a result of this continued electric growth, the share of residential energy provided as electricity is projected to increase to about 31 percent in 1990 and 35 percent in 2000. In contrast, total consumption of fuels other other than electricity is projected to hold essentially constant until 1985 and then decline slowly so that, by 2000, it will be about 10 percent below that for 1980.

Gross energy consumption

In contrast to the peaking out of net energy use, the gross amount of energy used for the residential sector will continue to grow through the end of the century, as shown in table 9. Between 1977 and 2000, gross energy use is projected to increase 32 percent, for an average growth of 1.2 percent a year over the period, but will slow from 2.6 percent a year through 1980, to 1.3 percent a year in the 1980s, and less than 0.7 percent in the 1990s.

Summary

Net energy consumption by the residential sector is projected to grow slightly, to just over 11 quads, by the mid-1980s, and then hold essentially constant through 2000. This leveling off is projected, despite substantial increases in numbers of households, because of significant improvements in the efficiency of heating energy use in existing residences, and dramatic reductions of heating energy requirements for new structures.

The extent of electrification of the residential sector is projected to continue to increase, reaching 31 percent of net energy consumption in 1990, and 35 percent in 2000. Because of increasing electrification, gross residential energy use is expected to continue to grow, though at a slowing pace, averaging 1.2 percent per year 1977-2000, but less than 0.7 percent per year in the 1990s.

UNCERTAINTIES IN THE ANALYSIS

Many factors contribute directly or indirectly to the trends in residential energy use developed in this study. Changes in these factors could result in changes in the overall trends. To assess the "accuracy" of these trends it is necessary to

--estimate the plausible range of values for each factor and

--determine the resulting changes in residential energy use.

These determinations should allow identification of (1) the factors which must be tracked closely to see if actual use is deviating from the projected trends and (2) the factors which new or modified energy policies should focus on, in order to maximize the effects of these policies on reducing residential energy use.

The factors can be separated into two groups; those which describe the numbers, types and locations of homes, and those which describe the intensity of energy use within the homes. The following paragraphs summarize the analysis of these uncertainties.

<u>Housing characteristics</u>

<u>The total number of households</u> in 2000 is quite likely to be within 2 or 3 percent of our projected value, because the persons who will head these households are essentially all living and in the U.S. now, and their household formation behavior appears to be predictable within relatively narrow bounds. Because energy use in new housing in the 1990s will only be about 64 percent of the average for all households, the effect of this range on residential energy use in 2000 would be a maximum of 1.3 to 1.9 percent. Thus, this factor is not an important source of uncertainty in the projection, barring major unpredictable events such as war, epidemic, natural disaster, massive new immigration, or major economic reversal.

<u>The rate of retirement of existing homes</u> will only weakly influence residential energy consumption: if retirements changed by 25 percent from our estimate, it would change residential energy consumption in 2000 by less than 0.5 percent. The probability of the rate's differing significantly from our estimate is low in the 1980s, because a continued high rate of household formation will maintain the demand for housing too high to allow large numbers of units to be retired due to excess vacancies. Even if the retirement rate were to double in the 1990s, which might be a plausible upper limit with decreasing household formation, it would lower the projection of residential energy use in 2000 by only 1.2 percent.

<u>Preferential retirement of less energy-efficient homes</u> is likely to a moderate extent, since structures in worse condition are more likely to be chosen for demolition. However, a substantial share of retirements occur because a site is converted to other uses (e.g., public works, or commercial or industrial development) independent of the condition of the home. Hence, preferential retirement can only have a relatively small influence on energy consumption, because it would only cause a fractional difference in one of several components of change in total consumption. A test calculation (See app. III.) indicates that preferential retirement would not be likely to effect residential energy consumption in 2000 by even as much as 0.5 percent.

The size of new housing units can only have a rather small effect on the projection, because it would mainly affect only their heating requirements, which, because of higher efficiencies, are only projected to account for 13 percent of net residential energy use in 2000. Thus, an average change of 5 percent in new unit size would only cause a 0.65 percent change in residential energy use at the end of the projection period, and less at earlier times.

While the size of new homes grew substantially in the post-World War II decades, this growth slowed sharply in the mid-1970s and we do not anticipate it will likely resume, because of reductions in numbers of persons per household and escalation of housing costs. In fact, there are some indications that new units may actually become smaller in the coming years.

We will note here that, by using the heating requirements of 1,600-square-foot single-family detached houses to characterize all new units, we have probably introduced an overestimate into the projection of residential energy use. The size of this overestimate grows over the projection period, reaching a total of about 2 percent of total residential energy use by 2000. Rather than correcting for this overestimate, however, we have let it stand, to approximately balance a potential underestimate from the efficiency of heating in new units, which will be discussed on page 33.

The types of housing units in the new stock to be constructed can only have a small influence on the projection. This surprising fact arises because, as already noted, new units will only account for 36.4 percent of the stock in 2000 and will use much less energy per unit for heating than currently existing ones. Therefore, a fractional change in the consumption per unit between types of units will affect only a small part of total consumption. A test calculation (see app. III.) indicates that, for a range of possible mixes of housing types (single-family detached houses, townhouses, mobile homes and apartments) likely to span the actual mix, the total range of effects on residential energy consumption at the end of the projection period will span only $\pm$ 0.5 percent.

Internal migration between sections of the country can only have a small effect on the projection, because it will only influence heating energy use in new units. Because new units are expected to use much less energy for heating than existing ones, the entire internal migration of population projected from 1977 through 2000 in this study is responsible for a maximum change in residential energy use of only about 1 percent, smaller even than the moderate energy use effects due to internal migration in the 1960-77 period. The scale of population shifts that would be necessary to make substantial impacts on residential energy consumption are quite large. We believe that the actual population shifts are unlikely to be more than 50 percent higher or lower than those projected, and therefore the overall effect on residential

energy use in 2000 from this uncertainty should be within about 0.5 percent, an essentially negligible amount over this long projection period.

Intensity of energy use in homes

The amount of nonheating energy used per residence was assumed to remain constant over the entire projection period at a level estimated from studies of energy use in 1970. In 1977, this amounted to 33 percent of residential energy use and by 2000 its proportion grows to nearly 43 percent. Any uncertainty in this term will make a substantial contribution to the uncertainty in the overall projection: if nonheating energy use per home differed from our assumption by 10 percent in 2000, then residential energy use would be changed by 4.3 percent.

Present trends, however, lead us to anticipate that this term will not change substantially over the projection period, because there are two strong forces working to drive it in opposite directions. We do not now see any compelling evidence that either of these trends--increasing numbers of air conditioners and steadily improving efficiency of most appliances--is likely to overcome the other. We, therefore, judge this factor as not likely to be subject to much uncertainty, possibly on the order of ±3 to ±5 percent, contributing perhaps 1 or 2 percent to the uncertainty of overall consumption. We would, however, want to watch over time for two possibilities that could change this judgment.

One would be a significant slowdown or reversal in the expansion of air conditioner installations. The other possible "wild card" to watch for would be the successful development and subsequent wide deployment of innovative types of water heaters, either solar or heat pump powered which, in tests, appear capable of using half as much net energy per unit or less for water heating than the average existing types. We focus on innovation in water heaters because they alone account on average for nearly half of total nonheating energy use in present homes. Therefore, a major drop in their energy requirements would make enough difference to affect the total quite significantly, which is not likely to be true of any other single nonheating end use. At present, there is a good deal of activity underway seeking to bring both of these types of water heaters into the market, but they have not yet succeeded commercially. 1/ In the future, we would want to track the progress of these efforts, with an eye to modifying the projection downward if these or other types of truly innovative major appliances begin to penetrate the market significantly.

1/A report in the EPRI Journal (Nov. 1980, p. 29) indicates that at least three firms have begun marketing heat pump water heaters.

The heating energy consumption of new residences built after 1977 is projected to average well under half the present value for existing homes. Thus, even though new structures are expected to compose some 36.4 percent of the housing stock by 2000, we project that it will only take 13 percent of total residential energy to heat them. Therefore, uncertainty in this factor will have only a moderate effect on the overall projection.

We regard this factor, however, as subject to a rather large uncertainty of an unsymmetrical nature. In the upward direction, we would not be surprised to see actual houses using substantially more energy than design estimates would indicate, both because of slow and uncertain progress in promulgation and enforcement of standards which we noted in a previous report 1/ and because of minor imperfections in construction which all too often can allow significantly greater heat losses than anticipated in original designs. 2/ As a rough estimate, we set this uncertainty as possibly going as much as one third above the projection for heating new units, up to more than 4 percent of residential energy use in 2000.

In the downward direction, we believe that the limiting level of improvement of heating in new housing would be for the average of these structures to actually perform at the BEPS levels by about 1985 rather than 1990, and then for some further improvements in subsequent construction to bring the average for the 1990s down by about another 25 percent. The effect of these improvements would be to lower residential energy use in 2000 by a maximum of 2 percent, compared to the more than 4 percent upward uncertainty just noted. This greater possibility of upward as opposed to downward deviation can be regarded as resulting in some underestimate in the overall projection. Rather than correcting for it, we have let the underestimate stand, where we believe it will roughly balance an overestimate introduced (as previously noted on page 31) by our use of the heat requirements of single-family detached houses to represent the requirements of all new units.

Energy consumption for heating existing homes has been assumed to decrease by more than 19 percent, from a 1977 average of 92.2 million Btus per year to a level of 74.4 million Btu's per year in 2000. This leaves the heating of homes remaining from 1977 and earlier still projected to consume 44.2 percent

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1/U.S. General Accounting Office, "Uncertainties About the Effectiveness of Federal Programs to Make New Buildings More Energy Efficient," EMD-80-32, Jan. 28, 1980.

2/"Saving Energy in the Home," R. H. Socolow, Ed., Ballinger Publishing Co., Cambridge, 1978.

of all residential energy in 2000, slightly higher than the share for nonheating uses and thus the largest of the three terms which make up total residential consumption. Therefore, uncertainty in this term can have a substantial effect on uncertainty in the overall projection; if actual heat requirements for houses pre-dating 1977 differed by 10 percent from levels that we have assumed, then net residential energy use would be changed by 4.4 percent in 2000. It should further be recognized that the effect of a given percentage uncertainty in this term would be even greater at earlier dates, because the share of total residential energy used to heat these homes is projected to be declining progressively from 67 percent in 1977.

In contrast to nonheating energy, the other large term in the sum of total consumption, we believe that there is substantial room for uncertainty about the extent and rate of reduction in the heating demands of existing homes. Indeed, while it would be misleading to explicitly quantify it, we judge that the uncertainty in this term will grow steadily over the projection period and is likely to already be as large as all other uncertainties combined by about 1990, near the mid-point of the projection period, with further growth possible over the following decade.

The rate of improvement in the efficiency of heating existing houses which we assumed for the projection was laid down with this uncertainty very much in mind; we set a rate which we believe, from recent trends and present indications, is the most likely course over the coming years. We are well aware that some conservation researchers 1/ have contended, on the basis of a few careful retrofits in limited types of residences, that the energy for heating existing buildings could be halved from 1975 levels by 1990. On the other hand, we know the extreme diversity of the existing housing stock, and the difficulties, both physical and institutional, that are likely to constrain the actual accomplishment of anything like this level of improvement.

Summary

Nine factors contribute to the overall uncertainty of our projection. They are listed in table 10 which shows, for each factor, the estimated range of uncertainty in the factor itself and the maximum contribution the factor can make to the uncertainty in total residential energy use.

Of the nine factors, four of them--preferential retirement among older structures, changing sizes of new homes, changes in the mix of types of new homes, and changes in the rates of internal migration in the U.S.--can only affect the overall projection by a maximum of about 0.5 percent each. These are essentially

1/M. H. Ross and R. H. Williams, "Drilling for Oil and Gas in Our Buildings," Report PU/CEES 87, Princeton University Center for Energy and Environmental Studies, July 1979.

negligible effects in a projection running over more than 20 years. Three other factors--the total number of households, the overall rate of retirement of existing housing units, and the amount of energy per household used for purposes other than heating--contribute to uncertainty in the overall projection to the extent of between 1 and 2 percent each.

When the effects of these three and the previous four are combined by the usual methods of statistical error estimation (See app. III.), the result is that their errors contribute a total which grows over time to a maximum uncertainty of 3.2 percent in total projected net residential energy consumption in 2000. This would be an extremely satisfying level of accuracy in such a long-term projection. The remaining two factors, however, make larger individual contributions to the overall uncertainty. One, the heating energy for new residences, makes a contribution which grows to an estimated 3 percent in 2000, and is thus about as significant a source of uncertainty as the combined effect of the previous seven factors.

Finally, the extent of efficiency improvement in the heating of existing homes makes a large contribution to the overall uncertainty of the projection for which we presently lack sufficient information to make a precise quantitative estimate. However, we judge that the uncertainty arising from this factor, which will also increase with time, will likely be as large by 1990 as the effects of all other factors combined, and will then outpace the others through the balance of the projection period. We therefore regard the trends in retrofitting of existing homes as by far the most important ones to watch in the coming years.

The achievement of substantial energy conservation through retrofit in the residential sector will require that millions of consumers implement a wide variety of conservation measures. As we concluded in a recent report, 1/ on-site energy audits will be needed to effectively inform consumers of available conservation opportunities. To the extent that such efforts are successful, the retrofitting process could be accelerated. As our report noted, the federally mandated Residential Conservation Service (RCS) is of particular importance to this process, since it is estimated that by 1985 nearly 95 percent of the residential sector would be offered RCS audits. Therefore, carefully tracking efforts to carry out on-site audits, as well as other evolving programs which can tailor retrofitting to the identified needs of individual residences on a large scale, are likely to give the best indications of how accurate our estimate of this most significant trend, and of total residential consumption, will prove to be.

1/U.S. General Accounting Office, "Residential Energy Conservation Outreach Activities--A New Federal Approach Needed," EMD-81-8, Feb. 11, 1981.

Table 10

Factors Contributing to Uncertainty in Projected Residential Energy Use

Factor	Maximum estimated range for factor	Maximum contribution to overall uncertainty
Total households	Small--2 to 3 percent	1.3 to 1.9 percent
Retirement rate	Moderate overall; maximum effect: double in 1990s	1.2 percent
Preferential retirement	Moderate (See app. III.)	0.5 percent
Size of new homes	5 percent - (May be more likely to go down.)	b/0.65 percent
Types of new homes	Moderate (See app. III.)	0.5 percent
Internal migration	50 percent of projected value	0.5 percent
Nonheating energy per household	a/Small--3 to 5 percent	1 to 2 percent
Heating energy for new units	33 percent	b/3 percent (+4 to -2)
Heating energy for existing units	Moderate, but growing over time	Growing; as large as all others combined by 1990.

a/Small because is net of two opposed trends. These can be watched independently, to see if one or the other is changing (See p. 32).

b/Size of new homes includes probable overestimate, heating energy for new homes includes probable underestimate; the two are left to approximately balance.

COMPARISON WITH OTHER WORK

Few studies explicity present trends in residential energy use; they usually present trends in energy use for a combined residential/commercial sector. Furthermore, sometimes residential trends are presented only in terms of gross energy demand, with limited information which allows it to be converted to net energy. As a result, direct comparisons with other work must be quite limited.

Table 11

Residential Energy Use Trends from Selected Studies

(quads)

	Net energy		Gross energy			
Year	DOE/EIA (note a)	GAO	IEA	OTA (note b)	DOE/EIA (note a)	GAO
1980	-	10.71	-	-	-	16.97
1985	10.31	11.05	-	-	16.77	18.32
1990	11.05	11.10	-	-	18.63	19.38
1995	11.80	11.09	-	-	19.99	20.00
2000	-	11.20	21.8-29.1	21.8-24.7	-	20.74

a/DOE/EIA mid-range estimate, plus conservation actions and 60 percent of renewable energy use.

b/Likely limits of actual consumption, from wider range of possible scenarios (See p. 38.)

We have compared our results with those of three other studies done by the Institute for Energy Analysis (IEA), 1/ the Office of Technology Assessment (OTA), 2/ and the Department of Energy's Energy Information Administration (DOE/EIA). 3/ However, only the DOE/EIA analysis projects the trends in net energy use. The projected trends in residential energy use from these three studies, along with the results of this study, are shown in table 11.

From a gross energy standpoint, our projection for 2000 appears to be somewhat below the range indicated by the IEA and OTA studies. However, these studies were both done before the dramatic increases in world oil prices that followed the Iranian oil cutoff. Recent discussions with IEA staff indicated that, in light of recent events, they would now regard the low scenario as their most likely projection. Taking into account the fact that even the low IEA scenario envisions much higher levels of electrification than our projection, leads to the conclusion that the GAO and IEA projections are relatively compatible, with the IEA projection showing somewhat lower net energy use and higher gross energy use than our estimate.

Comparison with the OTA projections is more difficult since OTA's study actually showed scenarios ranging from 15.4 to 48.4 quads of gross residential consumption in 2000, depending on a number of factors including prices. We selected as the top of the range for comparison one scenario, leading to 24.7 quads of gross consumption in 2000, based on a constant level of energy use per household which the OTA report implied was likely to be an upper limit on future residential consumption.

At the other extreme, OTA indicated that the economic optimum, which minimized the total combined costs of energy and conservation measures, would be a lower limit which actual consumption would probably exceed. Gross residential consumption of 21.8 quads in 2000 was OTA's estimate of that lower limit, but that was based on moderate future price projections.

Subsequent to OTA's report, however, residential oil prices by late 1979 climbed to levels not expected in the OTA high price projections until 1990 or later. Accounting for higher prices would, of course, have led to a drop in the lower limit estimated in the OTA study, and would likely bring the OTA range down to include our projected gross residential consumption for 2000

1/E. L. Allen, "Energy and Economic Growth in the United States," MIT Press, 1979.

2/Office of Technology Assessment, "Residential Energy Conservation," Report OTA-E-92, (July 1979).

3/Energy Information Administration, "Annual Report to Congress 1978," Department of Energy, Report No. DOE/EIA-0173/3, vol. 3 (1979).

within OTA's range of probable values. Discussions with OTA staff indicated that they agree with this interpretation.

Comparing net energy use projections, the DOE/EIA estimates are somewhat lower than our estimates in 1985. This is because the DOE/EIA estimates are optimistic regarding the ability of the Nation's housing industry to achieve the BEPS standards. For reasons explained earlier, we recognize the possibility of reaching the BEPS levels, but we do not believe that, at this time, such optimism is a prudent planning basis. On the other hand, by 1990 the DOE/EIA estimate is comparable to ours, and by 1995 is almost 6 percent higher. The major reason for this is that the DOE/EIA analysis assumes that residential retrofitting would slow substantially in the absence of explicit governmental programs, while our estimate includes continued, and in fact accelerated, retrofitting until 1990, and then only a gradual slowdown in the 1990s.

After we had completed this study, we obtained more recent projections from DOE/EIA. 1/ The midcase projections in this updated version lie somewhat below ours throughout the period, showing total net residential energy consumption of 10.6 quads in 1985, 10.7 in 1990, 10.6 in 1995, and 10.5 (excluding wood) in 2000.

1/Energy Information Administration, "Annual Report to Congress 1980," Department of Energy Report No. DOE/EIA-0173(80)(3), Vol. 3, 1981.

CHAPTER 5

SUMMARY AND OBSERVATIONS

Net energy use in the U.S. residential sector has fallen steadily relative to overall U.S. net energy consumption, from 18.8 percent in 1960 to 16.7 percent in 1977. However, the increasing electrification of the residential sector has held the sector at a constant 20 percent of overall gross energy use.

SUMMARY

--The dominant factors in determining trends in U.S. residential energy use are (1) the growth in the number of households, (2) the effectiveness of conservation actions, and (3) the expected electrification levels in the residential sector.

--The rate of household additions will slow substantially by the end of the century. Therefore, new structures are likely to represent a decreasing proportion of the housing stock, which will limit the impact that energy efficiency improvements for new housing can have on U.S. residential energy use.

--Homes existing in 1977 will likely account for a substantial majority of the U.S. housing stock in 2000. As a result, the most significant factor affecting U.S. residential energy use will be the extent to which the heating efficiency in these homes can be improved.

--Even before supply uncertainties and increases in energy prices became serious, with the Arab oil embargo of 1973-74, growth in U.S. residential energy use had already slowed significantly, starting in 1970.

--The growth in net U.S. residential energy use will virtually cease after the mid-1980s.

--Plausible changes in the relative distribution of housing types built in the next 2 decades (i.e., single-family, multi-family, and mobile homes) are unlikely to have substantial effects on U.S. residential energy use through 2000.

--Regional migration has had relatively little effect on net energy use in the residential sector to date, and is expected to be even less significant in the future. However, it has had a more significant effect on the fuel mix used by the residential sector, a trend which is expected to continue in the future and which could affect gross residential energy use.

--Based on current trends, electricity is expected to account for 35 percent of net residential energy use by the end of the century, up from less than 22 percent in 1977.

--Because of the increasing electrification of the U.S. residential sector, gross energy use will continue to grow, although at a slowing pace, through the end of the century. The rate of increase is projected to average about 1.2 percent per year from 1977 to 2000, but will go from an estimated 1.9 percent annually for 1977-1985 to only 0.7 percent per year for the 1990s.

OBSERVATIONS

Price Effects

Our estimate of future residential energy use did not take energy prices into account explicitly. However, the assumptions we used, regarding the rate of future efficiency improvements by retrofitting and equipment replacement, were based on judgments made since the second major round of world energy price increases, which followed the Iranian oil cutoff of 1979. Thus, major movements in prices have been taken into account implicitly, to the extent that they stimulate what economists speak of as changes in the capital stock of energy-using equipment.

Two other types of price effects which may occur have not been taken into account: short-term consumer decisions to make do with less in the face of large sudden price increases, and longer term decisions by consumers to limit the share of household resources spent on energy services by changing their life-styles (i.e., changing expectations rather than changing equipment).

Regarding the short-term effects, it is clear that they occurred in 1973-74, as evidenced by sharp decreases in energy use per household discussed in chapter 3. Unpublished data, mentioned to us by a number of analysts who commented on a draft of this study, appear to show that there were similar substantial drops in heating energy use in the 1979-80 heating season, as compared to 1978-79, in the wake of the price shock following the Iranian oil cutoff. However, based on our examination of trends following the 1973-74 price shock in a number of consumption sectors, we believe that short-term reductions in levels of service largely do not persist. Instead, we believe consumers tend to make gradual improvements in their energy-using equipment, in a sense buying back their previous levels of comfort and service through capital investment rather than fuel purchases.

To the extent that this is correct, short-term drops in residential energy consumption in the immediate wake of sharp price increases would not affect the long-term trends estimated in this study. Rather, they would only influence the short-term

shape of the consumption curve, making it move irregularly rather than smoothly over time. Therefore, we would not attach much importance to the likely finding that residential energy consumption for 1980, after it is separated out from commercial consumption and corrected for effects of the recent recession, may be lower than our estimate. Only a continued trend away from our projection, rather than fluctuations around its trend line, would be cause to reexamine the analysis.

Long-term changes in residential consumer life-styles, to reduce levels of energy service in order to limit spending in face of price increases, have not been estimated or included in this analysis. Data from which the extent of this effect might be estimated in actual experience, rather than only from theoretical principles, would be a very important contribution to a better ability to project our energy future. DOE's Energy Information Administration has started to collect such data, but only the first year's results have been published so far, 1/ so changes in levels of service cannot yet be estimated from a consistent data series. Rather than guessing at the extent to which there will be such life-style changes, we have estimated the consumption levels to be expected with no reductions in levels of service. To the extent that there are long-term reductions, then the trend line for residential consumption in our estimate would be lowered.

Supply effects

This analysis assesses future U.S. residential energy use in light of current U.S. residential fuel use trends. These trends, however, can be significantly affected by changes in fuel availability. A simplified examination of the balance between fuel availability and residential consumption trends, we believe, can provide a basis to draw some broad policy implications.

In 1977, virtually all residential energy purchases were in the form of petroleum products, natural gas, or electricity, with coal providing only a fraction of a percent. 2/ Our analysis of trends in residential energy consumption, presented in table 9 in the previous chapter, shows that electricity use in the residential sector will grow steadily through the end of the century, although at decreasing rates. On the other hand, the demand

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1/Energy Information Administration, "Residential Energy Consumption Survey: Consumption and Expenditures, April 1978 through March 1979," Department of Energy Report No. DOE/EIA-0207/5, July 1980.

2/EIA data does not count wood, but with Census data showing only 1.6 percent of households using wood as heating fuel, and those predominantly in milder climates, the contribution from wood is likely less than 1 percent of total residential energy.

for other fuels, virtually all met by petroleum and natural gas at present, is projected to have increased slightly through 1980, and to then decline steadily through 2000, to a level 0.86 quads below the projected 1980 consumption level. Allowing for the projected increase from 1977 to 1980, the estimated demand for fuels other than electricity would be about 9 percent lower at the end of the century than in 1977.

Despite this expected decline in requirements for fuels other than electricity, it may not be possible to meet the demand with oil and gas in 1990 without additional imports. One of our recent reports indicated that conventional U.S. petroleum and natural gas output will decline more than 17 percent by 1990, and recover only slightly by 2000 to a level 15 percent below 1978 production. 1/ The sharp decline in the 1980s is significantly faster than the projected rate of decline in residential use of non-electric fuels, whereas the problem of diminishing supplies does not appear to raise further problems in the 1990s.

In 1977, the residential sector directly used 7.97 quads, or 14 percent, of the total petroleum and natural gas consumed in the U.S. In that year, 33 percent of U.S. oil and gas consumption was from imports. Attributing the overall 33-percent imports equally to all sectors would indicate that the residential sector in 1977 can be viewed as having used 2.63 quads of imports and 5.34 quads of domestic oil and gas.

If, in 1990, the residential sector maintained its 14 percent share of the decreased domestic oil and gas production, then it would receive only 4.44 quads. Providing the balance of the 7.71 quads of non-electric net energy projected to be consumed by the residential sector in 1990, as shown in table 9, would require another 3.27 quads from imports and other sources. Therefore, allowing for continuation of the 1977 levels of residential coal and wood use, imports of petroleum and natural gas would have to increase by 0.55 quads if they alone were to provide the remainder of residential fuel supplies.

This estimated gap of 0.55 quads in 1990 is approximately 5 percent of the 11.1-quad net consumption projected for the residential sector in that year, which puts the gap at about the limit we estimated for the uncertainty of our residential consumption projections. While this means that our projection cannot be taken as a certain indicator of the occurrence of such a gap, it does suggest the likelihood that the residential sector could provide some upward pressure on oil (and/or gas) imports through the 1980s.

1/U.S. General Accounting Office, "Analysis of Current Trends in U.S. Petroleum and Natural Gas Production," EMD-80-24, Dec. 7, 1979.

Current U.S. energy policy has been aimed at reducing imports or at least not allowing them to exceed recent levels. In this context, much debate has arisen about the feasibility and potential consequences of a "zero energy growth" future. While we have not completed our consumption projections, we suggest that, at least in one major sector, very low, near-zero growth in net energy consumption is likely to be achieved. Yet, faced by very probable continued declines in domestic oil and gas output, the levels of imports required for this sector could increase somewhat during the 1980s even with a zero-growth future.

The Nation might avoid imports for the residential sector by a combination of any of the following paths:

--Increased energy supplies from new or revived energy sources, including synthetic fuels, solar energy, and unconventional oil and gas.

--Efficiency improvements more successful than those included in our estimates.

--A greater extent of electrification of residential energy use than is indicated by current trends, with a corresponding further expansion of electricity generation.

--Changes in residential consumer life-styles, which result in the use of lower levels of energy services.

While any or all of these paths may be followed, none appears easy or certain, and all are likely to involve unanticipated delays and problems. Restraining or reducing energy imports in the 1980s is likely to require continued efforts to facilitate progress on all these fronts.

Residential energy conservation

Focusing more closely on energy consumption in the residential sector, and the prospects for reducing it by efficiency improvements, our analysis divided energy use in the sector into three portions: heating in newly built residences, heating in previously existing ones, and nonheating uses.

Efficiency improvements already underway and expected in new residential construction, combined with demographic changes which will likely slow the rate of construction substantially over the balance of this century, lead us to estimate that only about 13 percent of net residential energy use in 2000 will go to heat homes built after 1977. Rather than the heating of new homes, it is nonheating energy uses, at 43 percent, and heating of homes already in existence in 1977, at 44 percent, which are estimated to take the major shares of residential energy in 2000.

Improvements by the construction and appliance manufacturing industries (already occurring under stimulation both from consumer concern about energy costs and from governmental actions on labeling, goals, and possibly standards) will continue to upgrade the efficiency of energy use in new homes and in nonheating uses. In contrast, improvements in the heating efficiency of existing homes will require actions by millions of consumers. The extent to which the private sector will respond to realize gains in heating efficiency in existing homes, and the effectiveness of any Federal initiatives directed at this target, are major uncertainties at this time.

Thus, the heating of existing homes is the largest target for efficiency improvements, and yet is the area of residential energy use for which improvements appear most uncertain. For these reasons the improvement of heating efficiency in existing homes should be the focus of greatest Government policy attention in the residential sector, aimed at assisting our finding both the most effective retrofitting measures to take, and the most effective institutional approaches to identify and deliver these measures.

GEOGRAPHIC HOUSEHOLD PROJECTIONS

Projections were made for migratory pattern II-A as follows:

1. Estimate the percentage of the population which is 22 or over for each year of the projection period using Census Bureau Series II national population projections.

2. Multiply the Census Bureau's divisional population projections by the appropriate percent, giving the number of people in that division who are 22 or over (adult population) for each year of the projection period.

3. Using the adult-population-to-household ratios calculated on the national level for each year of the projection period, and the projected divisional adult population, calculate the number of households in the division.

The projections resulting from this process were then plotted graphically in a time series with the historic values for each region. The graph of the Pacific division showed a discontinuity between the last observed point (1977) and the first projected value (1980). This indicated to us that the assumptions we made did not hold true for the Pacific division--that is, the percent of the population in the age group 22 or over differs from the national average and/or the pattern of household formations in the Pacific division does not track the national pattern.

To correct the problem, the projection process was applied to actual population data in the 1970 and 1972-76 period and the results were compared to the observed number of households in each division. The projections were consistently low for the Middle Atlantic, Pacific, and West North Central divisions and consistently high for the other six divisions. Projections for the Pacific division, which showed the largest variance, differed by a high of 6.5 percent in 1975. No other division differed by more than 3.1 percent over the period. The South Atlantic division consistently showed negligible variance, coming as close as projecting 11,221,000 to an actual 11,227,000 in 1975.

A correction factor for each division was calculated by taking the ratio (observed value/projected value) for each year of the period (1970 and 1972-76) and averaging the results. Table I-1 shows the correction factors and the percent deviation from the national pattern. The factors indicate that the pattern of household formation on a divisional basis closely approximates the national pattern except in the Pacific division where households average 6 percent higher than the national rate. We know of no reason for the higher level of household formation in this division other than differing social trends or possibly the presence of large cities where one-person households are not uncommon.

Table I-1

Divisional Correction Factors

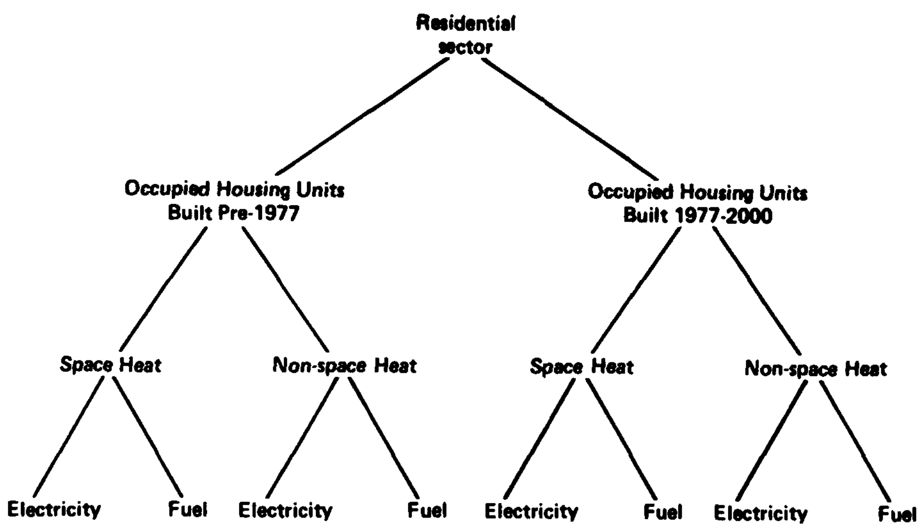
Division	Correction factor	Percent deviation from national pattern
East North Central	0.990	1.0 lower
East South Central	0.973	2.7 lower
Middle Atlantic	1.023	2.3 higher
Mountain	0.980	2.0 lower
New England	0.993	0.7 lower
Pacific	1.060	6.0 higher
South Atlantic	0.996	0.4 lower
West North Central	1.020	2.0 higher
West South Central	0.992	0.8 lower

RESIDENTIAL ENERGY USE

CALCULATION METHOD

Our analysis estimated expected trends in residential energy use separately for housing existing in 1977, and for new housing to be built from 1977 to 2000. Energy use within each housing category was separated into energy use for space heating and non-space heating (hot water, air conditioning, cooking, appliances, lighting, etc.). We allowed for improved efficiencies in all end-uses of energy in the residential sector. All uses were also analyzed in terms of two broad energy types--electricity, and all other fuels (the sum of natural gas, fuel oil, bottled gas, coal, solar energy, etc.). The following overview depicts the framework for our analysis.

Analysis Framework



HOUSING UNITS

Our analysis differentiated between housing units built before and after 1977, due to the differences in the energy-consuming characteristics of the structures, particularly for space heating. Most pre-1977 housing was constructed with relatively little attention to the efficient use of energy. Improving the efficiency of energy use in these homes will require retrofit conservation measures.

On the other hand, new housing units are increasingly incorporating improved energy-consuming characteristics into their original design and construction. This is the result of a number of forces, including price-motivated consumer demand and progressive upgrading of Government regulations.

Another reason for differentiating between pre- and post-1977 structures stems from differences in the rates at which change can occur in the two types of housing. This includes the rate of efficiency improvement in pre-1977 housing, the rate of upgrading new building standards, and the rate of achieving those new building standards. Thus, in addition to differences in present and potential efficiency levels in existing and future homes, the rate of improvement is also likely to differ between the two types.

Retirement of existing housing

The rate at which existing housing units are permanently removed from the housing stock is somewhat uncertain. Current estimates span a range from 0.5 percent to 2 percent of the occupied housing stock per year (350,000 to 1.5 million units per year). The divergence is largely due to uncertainty regarding the numbers of units retired in a year that re-enter the housing market in subsequent years, as well as non-residential structures converted to residential use. We have chosen to utilize a rate which attempts to account for the extent to which abandoned housing and other existing structures (e.g., commercial structures converted to loft apartments) re-enter the housing stock. Over the period 1973-77, the apparent national rate of housing unit abandonment averaged 700,000 units per year, or approximately 1 percent of the housing stock. This rate is consistent with some other housing studies. On the other hand, when re-entry of abandoned housing and conversion of other building types to residential use is taken into account, the net retirements averaged only about 350,000 units a year, or approximately 0.5 percent of the existing housing stock a year.

Our analysis uses the net retirement rate of 350,000 units per year observed over the period 1973-77 for the retirement rate of existing housing units through the end of the century. Using this rate, we calculated that 8.05 million units would be retired over the period 1977 to 2000. For simplicity, we have assumed that all retirements until 2000 will be of units that were in existence by 1977.

Housing constructed from 1977 to 2000

The low rate of net retirements contributes to a relatively low rate of new housing additions. The number of newly constructed occupied units was calculated in each year by subtracting the remaining number of previously existing occupied units from the projected total number of households in that year. The resulting new housing additions are shown in table II-1. The table indicates a sharp rate of decline in new housing additions over the remainder of the century. This is due to declining rates of household formation combined with the low rate of housing abandonment described above.

Table II-1

Average Annual Additions of New Units to Housing Stock

	Millions of units
1977-1980	2.15
1980-1985	1.91
1985-1990	1.77
1990-1995	1.37
1995-2000	1.29

It should be noted that this calculation gives the number of occupied new units. Since vacancies generally occur in new as well as old units, this implies that the number of housing units built in each period will be larger than the number occupied, possibly on the order of 5 percent or so. Also, such a demographically-based approach cannot be expected to reproduce fluctuations over short periods of a year or two, such as the drop in housing construction due to general economic conditions in 1974-76 or the present (1979-1981) drop in construction.

ENERGY USES

Our analysis divides residential energy use into heating and nonheating uses to isolate the effect of geographical weather variations on heating uses. Although nonheating residential energy use included air conditioning, which should also be sensitive to geographical variations, the data we obtained could not give clear evidence of geographical variations in energy use that could be attributed to air conditioning.

Non-space heating energy use

Our analysis of non-space heating energy use is based on the results of two studies undertaken by the Rand Corporation 1/ and Arthur D. Little. 2/ Both of these studies attempted to disaggregate non-space heating energy use into the quantities used for specific functions (e.g., heating water and cooking). Their results are shown in table II-2.

1/Stephen H. Dole, "Energy Use and Conservation in the Residential Sector: A Regional Analysis," Rand Corporation, June 1975.

2/Project Independence Blueprint, Task Force Report, "Residential and Commercial Energy Use Patterns, 1970-1990," Vol. I, Arthur D. Little Co., Nov. 1974.

Table II-2

Non-Space Heating Energy Use per Household

Census division	Rand	A.D. Little
	(million Btu's/year)	
New England	42.97	48.6
Mid-Atlantic	45.62	48.6
East North Central	44.64	48.6
West North Central	44.54	48.6
South Atlantic	39.23	46.6
East South Central	38.00	46.6
West South Central	49.36	46.6
Mountain	43.31	49.5
Pacific	40.04	49.5
National average	43.27 (mean=45.71)	48.15

One might expect non-space heating energy use to show relatively little variation within regions. Table II-2 shows that this is true in the A.D. Little study and generally true in the Rand study, with the exception of the Southern Census divisions. Most striking is the difference between the West South Central and East South Central divisions in the Rand study. These divisions, despite apparent similarities, have the highest and lowest non-space heating energy use per household, respectively. Climate similarities preclude variation in air conditioning uses being a major cause of this difference. Furthermore, there is little basis to suspect that geographical variation would affect other components of this category such as hot water usage or cooking. We believe that the most reasonable approach to contend with this unexplained variation is to regard it as the result of approximations and uncertainties in the available data. Therefore we have used the results in table II-2 to calculate a national average for non-space heating energy use. To obtain a national average, the values in table II-2 were weighted according to the number of occupied households in each Census division in 1970, when these studies were performed, and then averaged. The resulting average, 45.71 million Btu's per household per year, was utilized for the non-space heating energy consumption in our calculations.

This value was kept constant through the projection period. Although appliance efficiency is expected to improve through the end of the century, we expect that increased appliance saturation,

particularly air conditioning use, will counteract the increasing efficiency and maintain non-space heating energy use approximately constant. Table II-3 shows the increasing market saturation of central and room air conditioners, which indicates that there is still substantial room for growth in air conditioning use in the residential sector.

Table II-3
Air Conditioning Market Saturation-Residential Sector

	Central	Room (at least one)
1960 housing stock	995,874 (1.9% of all units)	5,587,631 (10% of all units)
1970 housing stock	7,262,982 (11% of all units)	16,938,514 (25% of all units)
1977 housing stock	18,075,000 (22% of all units)	23,589,000 (29% of all units)
1978 new houses completed	1,189,000 (64% of all units)	NA

Data sources: 1960 Census of Housing; 1970 Census of Housing; Current Housing Reports: Series H-150-77, "General Housing Characteristics for the United States and Regions: 1977," Sept. 1979; Construction Reports, Series C25-78-13, "Characteristics of New Housing: 1978," Sept. 1979. (All from U.S. Bureau of the Census.)

Space heating energy use

We estimated average space heating energy consumption for each of the nine Census divisions by subtracting the non-space heating energy use per household from the total energy use per household. This calculation was performed separately on 1975 and 1977 FEDS data by divisions. The results for the 2 years were then combined to give a raw estimate of space heating energy use.

Since the amount of energy required for space heating is highly dependent on weather conditions, it was necessary to normalize our raw estimated values to an "average" weather year. We did this by dividing raw estimated space heating energy use by the correction factors (the ratio of the two heating degree day averages) shown in table II-4.

Table II-4

Space Heat Correction Factors

Census Region	Mean HDD 1975&'77 (note a)	Mean HDD 1930-78 (note a)	Correction factor	Corrected space heating energy (million Btu's/year)
New England	6,403.5	6,484	0.98758	113.63
Mid-Atlantic	5,711.5	5,779	0.98832	100.43
East North Central	6,338.5	6,258	1.01286	140.18
West North Central	6,603.5	6,576	1.00418	127.10
South Atlantic	3,110.0	3,075	1.01138	51.03
East South Central	3,555.5	3,379	1.05223	71.22
West South Central	2,311.5	2,254	1.02551	80.67
Mountain	5,757.5	5,626	1.02337	90.63
Pacific	3,367.0	3,308	1.01784	53.69

a/Heating degree day information was obtained from NOAA - "State, Regional, and National, Monthly and Seasonal Heating Degree Days Weighted by Population (July 1931-June 1978)."

Conservation effects in existing structures

Expert opinion on the energy conservation potential of existing housing structures varies widely. Estimates of the technically achievable potential savings range from 20 to 50 percent of average use in the early to mid-1970s. It should be noted that our calculations indicate a reduction of 17 percent in average space heat energy requirements per household between 1970 and 1977, which suggests that a portion of the technically achievable saving has already occurred.

In this study, we have taken an intermediate stance, allowing for approximately a 20-percent reduction in average space heating energy consumption in previously existing structures between 1977 and 2000. Multiplied by the 17-percent reduction that occurred between 1970 and 1977, this amounts to a total reduction of about 33 percent from 1970 levels, about the mid-point of the 20- to 50-percent range of other studies.

Our assumed improvement implies an almost 1 percent per year average reduction in the space heating energy requirement of the total pre-1977 occupied housing stock. To achieve this would require retrofit achievements each year equivalent to reducing the space heating energy requirement of 2.3 million 1977 average homes by 33 percent. However, rather than implementing the reductions uniformly, we have phased them according to the schedule in table II-5.

Table II-5

Reductions in Average Space Heating Energy Consumption

Year	Reduction per year (percent)
1977-1980	0.5
1980-1985	1.0
1985-1990	1.5
1990-1995	1.0
1995-2000	0.5

Three factors lead us to anticipate an initially increasing rate of improvement:

--Growing interest in retrofitting as energy prices increase.

--Increasing development of the retrofit industry infrastructure.

--Experience leading to more effective retrofitting techniques.

We assume that the rate of improvement in average space heating energy consumption will peak and then begin to decrease in the 1990s, due to the completion of a large percentage of the easiest, most cost-effective retrofit actions. Remaining improvements thereafter are likely to occur at a slower rate.

Conservation effects in new structures

Space heating energy requirements for new housing in our calculation gradually change from average 1977 energy consumption levels to levels corresponding to the Building Energy Performance Standards proposed in 1979 for the average-sized 1,600-square-foot single-family detached home. 1/

The BEPS levels for heating energy consumption used in our calculations were obtained from graphs of energy consumption vs. degree days, which we made from data communicated to us by the technical group which developed the proposed BEPS standards for DOE. 2/ Heating energy values on each graph (one graph for gas-heated and one for electrically heated houses) were read off at

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1/"Notice of Proposed Rulemaking, Energy Performance Standards for New Buildings," Department of Energy Document DOE/CS/0112, Nov. 1979.

2/Energy and Environment Division, Lawrence Berkeley Laboratory, Jan. 1980.

the degree day level corresponding to the population-weighted degree day average for each Census Division. These values are shown in table II-6.

Table II-6

Heating Energy Consumption, Measured at Building Boundary, for 1,600 Square-Foot Detached House by Census Division

	Census Division	Heating Energy Consumption (million Btu's per year) Gas heated	Electrically heated
I	New England	59.60	25.12
II	Middle Atlantic	51.84	20.48
III	East North Central	56.80	23.04
IV	West North Central	60.80	26.00
V	South Atlantic	22.08	6.40
VI	East South Central	25.12	7.20
VII	West South Central	12.96	3.52
VIII	Mountain	50.56	19.52
IX	Pacific	24.96	7.04

These heating energy values are so far below those for existing residences (table II-4), that some explanation is warranted.

The BEPS levels were set to attain a minimum total combined cost of energy-saving measures and fuel over time. The model (calculated) structures, therefore, have for example, more insulation and multiple-glazing than is standard in present construction practice. The effect of such improvements is to greatly reduce the rate of heat loss from a structure. As a result, in a relatively mild climate, the heat obtained passively from the sun, and from appliances and persons in the structure, can provide a major proportion of the heat needed to maintain indoor comfort. This is the reason why BEPS levels of heating energy consumption are only a small fraction of the average for the present stock in the milder parts of the country: in the West South Central Census division, the gas- and electrically heated homes at BEPS levels are calculated to use only 16 percent and 4.4 percent as much energy for heating as the present average. In contrast, the colder climate of, for example, the West North Central division will impose a heating load, even on a well-insulated house, which will be much greater than the contributions of passive solar heating, appliances, and occupants. This will mean that a major proportion of the required heat would still have to be provided by an active heating system, so that in this division, houses performing at BEPS levels would require 48 percent (gas-heated) or 20.5 percent (electrically heated) as much energy as the average for present structures.

Electrically heated structures, in the proposed BEPS levels, would require less delivered energy for heating than gas-heated ones for three reasons.

First, the way the levels were set, to minimize costs, resulted in more tightly protected structures with electric heat, because of higher costs per unit of energy for electricity than other fuels. Second, with fuel heating, some part of the energy of supplied fuel is lost up the flue, while all of the electricity delivered goes to heating. Finally, the electrically-heated values are all based on the use of heat pumps, although they do not assume advances beyond present heat pump capabilities. According to the Lawrence Berkeley Laboratory group, heat pumps show seasonal Coefficients of Performance (COP), which range with climate from 1.38 in Minneapolis to 2.02 in Fresno and Burbank. (The COP is the ratio of heat provided to energy used to drive the pump, and the seasonal value is the average over the entire heating season in an average weather year.) Thus, the energy delivered to an electrically heated unit is multiplied by the local seasonal COP to give a measure of the heat actually provided.

Although DOE proposed to implement the BEPS standards within 1 year of final approval, we believe that it will take longer before the actual performance of housing matches BEPS levels, due to administrative and technical complexities.

Accordingly, attainment of BEPS levels in actual practice was phased in over the period from 1977 to 1990 in four stages. This series of improvements starts in 1977 for our analysis (despite the fact that BEPS could not now be promulgated until at least 1982) in recognition of energy efficiency improvements already being implemented in new housing. We have assumed that housing units constructed between 1977 and 1980 will have reduced their heating requirements by 25 percent of the difference between 1977 averages and BEPS levels. Those constructed between 1980-85 will have average heating requirements 50 percent of the way between 1977 and BEPS levels; 1985-1990, 75 percent; and units constructed in 1990 and beyond will finally achieve BEPS levels. Our method is shown in table II-7.

Table II-7
Space Heating Improvements
in new structures

Houses built	Space heat energy use (Note)
Pre-1977	a .
1977-1980	.75a + .25b
1980-1985	.50a + .50b
1985-1990	.25a + .75b
1990-2000	b

a = 1977 average space heat energy use

b = BEPS levels proposed in 1979

ENERGY SOURCE MIX

Energy sources were separated into two general categories, electricity and fuels (oil, natural gas, bottled gas, coal, and all others). Consideration of the mix becomes significant because of the declining prospects for fuel supplies such as natural gas and heating oil, and regional differences in fuel availability.

Non-space heating energy source mix

Only three non-space heating appliances offer a choice of energy supply: water heating, cooking, and clothes drying. It should be noted that gas central air conditioning is available, however it has not achieved a market share large enough to be significant in this analysis. All other appliances in this category are electric. It is also important to consider the total market saturation, i.e., the percentage of the occupied housing stock that has these appliances installed. Water heating equipment and cooking facilities have been maintained at 100 percent market saturation throughout the projection period. Clothes dryers were assumed to slowly increase their market share from 50 to 60 percent in equal increments from 1980 to 2000.

We explicitly calculated energy consumption only for the appliances offering fuel choice options. This calculated consumption was then subtracted from the total non-space heating energy in each division (i.e., 45.71 million Btu's per household per year multiplied by the number of households per division). The remaining quantity was considered to be the electricity utilized by the other unspecified appliances.

Efficiency considerations

In general, the efficiency of electric, as compared to fuel-powered appliances, is greater on a point-of-use basis. That is, on the average, electric appliances produce more useful work per unit of purchased energy than fuel-powered units, and will, therefore, consume less net energy to provide the same function. However, due to the lack of reliable data it was only possible to consider this effect for water heating. In our calculation, electric and fuel powered cooking ranges and clothes dryers utilize the same quantity of net energy for the first few years.

The efficiency of the appliance stock in use was allowed to improve in our analysis during the projection time span. The rate of improvement was based on DOE appliance efficiency targets, and what we judged to be realizable. We differentiated these rates on the basis of two factors: energy input and, after 1990, whether the appliance is installed in an old or new housing unit. Different rates of improvement were used for fuel and electric appliances because of the more substantial savings available for gas appliances by replacing pilot lights with electric ignition. Efficiency improvements were further differentiated, after 1990, between existing and new housing units because we felt that, by that time, the difference in appliance stock efficiency would be significant. Since new homes will, for the most part, be equipped with new, state-of-the-art appliances, their energy efficiency is likely to be better. While the same new appliances are factored into the existing houses as replacements, the rate and extent of improvement of the entire stock will be less due to the large number of older, relatively inefficient appliances remaining in service. Table II-8 shows the schedule for improvements utilized in the analysis.

Efficiency improvements in the appliance stock have an important side effect on the fuel mix of our analysis. Since the total non-space heating energy use remains constant throughout the projection period, any decrease in energy demand resulting from efficiency improvements in the three explicitly treated appliances will be absorbed by the unspecified, all-electric appliances. We anticipate that much of this excess will be utilized by the continuing expansion of the stock of air conditioners.

Appliances in existing houses

The fuel mix for water heating, cooking, and clothes drying was derived from a combination of the 1970 Census of Housing and the 1977 Annual Housing Survey. 1/ The fuel mix was kept constant

1/U.S. Bureau of the Census, "General Housing Characteristics for the United States and Regions: 1977, Annual Housing Survey: 1977, Part A," Current Housing Reports, Series H-150-77, Sept. 1979.

Table II-8

Average Appliance Stock Efficiencies
(Relative values: 1970=1.0)

	Water heating		Clothes drying		Cooking	
1970						
Electricity	1.0		1.0		1.0	
Fuel	1.0		1.0		1.0	
1980						
Electricity	.98		.97		.99	
Fuel	.95		.97		.95	
1985						
Electricity	.96		.96		.98	
Fuel	.92		.96		.92	
1990						
Electricity	.94		.94		.97	
Fuel	.89		.94		.89	
	Existing housing units	New housing units	Existing housing units	New housing units	Existing housing units	New housing units
1995						
Electricity	0.92	0.90	0.93	0.90	0.96	0.90
Fuel	.87	.80	.93	.90	.84	.79
2000						
Electricity	.90	.87	.92	.89	.95	.85
Fuel	.85	.77	.92	.89	.80	.75

during the time span of the projection, since we had no firm basis to project the type or extent of fuel switching.

Appliances in new houses

Appliances were added into the new units according to the fuel choice trends observed betwen 1970 and 1977. Newly installed water heaters are about half electric and half fuel-powered in all regions except the South, where electric water heaters accounted for about 75 percent of the new installations. Fuel choices for clothes dryers were kept at 70 percent electric, 30 percent fuel throughout the projection, while cooking was gradually increased from 41 percent electric, 59 percent fuel to 50/50.

Space heating energy source mix

Market shares of space heating fuel types in our analysis for existing housing were taken from the 1977 Annual Housing Survey. 1/ The regional values given by Census were applied equally to all divisions within a region. These proportions were maintained constant throughout the projection period by retiring all types of housing units at the same rate. No allowance was made for fuel switching, since the nature and magnitude of of this activity could only be estimated within the context of an overall assessment of U.S. energy supply and demand.

All new units were factored in at rates based on market shares taken from the 1977 data, and trends evident from 1978 construction. 2/ However, all new additions are considered to be powered either by electricity or "fuel." Any oil or other fuels--except gas and electricity--mentioned in the 1978 construction report was divided in half, with one-half added into each of the "fuel" and electricity shares. Oil heated units omitted by this approximation will, at least partially, balance those dropped due to fuel switching in existing units, which was not explicitly estimated.

Energy use per household for new structures at BEPS levels was given explicitly for electrically heated and fuel (gas) heated units in table II-6. For previously existing structures, the values for the two classes of fuels were computed by dividing divisional heating fuel use between electric- and fuel-heated units on the assumption that electric-heated units required

1/U.S. Bureau of the Census, "General Housing Characteristics for the United States and Regions: 1977, Annual Housing Survey: 1977, Part A," Current Housing Reports, Series H-150-77, Sept. 1979.

2/U.S. Bureau of the Census, Construction Reports, Series C25-78-13, "Characteristics of New Housing: 1978," Sept. 1979.

60 percent as much delivered energy as fuel-heated ones. Heat pumps would likely do better, but in 1977 they were too small a share to affect the calculations.

UNCERTAINTY ANALYSIS

General Method

When a numerical result, such as an estimate of residential energy consumption at a future date, is obtained by combining several terms, each of which is somewhat uncertain, then the result will have an uncertainty that is compounded from the uncertainties of the individual terms. The way in which such uncertainties or errors combine depends on the way that the terms are combined.

When terms are multiplied or divided to give a result, then the percentage uncertainty in the result is equal to the square root of the sum of the squares of the percentage uncertainties in the individual terms. 1/ This rule applies, for example, to combining the uncertainties in the sizes of new homes and the mix of types of new homes.

When terms are added or subtracted to give a result, then the absolute uncertainty in the result is equal to the square root of the sum of the squares of the absolute uncertainties in the individual terms. 1/ This rule applies, for example, to combining the uncertainties in the three separate terms which add up to total residential energy consumption: heating energy for pre-1977 residences, heating energy for residences built after 1977, and non-heating energy.

The second rule explains why two terms with large individual uncertainty ranges (internal migration: estimated range ±50 percent, and heating energy for new units: estimated range ±33 percent) make only relatively small contributions to the overall uncertainty in total residential energy consumption. The small absolute size of the contribution from each of these terms, compared to the overall result, means that even though their percentage uncertainties are large, the absolute size of the uncertainty contributed by each term is relatively small, compared to the size of the final result.

Test calculation--preferential retirement among existing structures

With the retirement rate of 350,000 units per year which we used, 8.05 million residential units will have been retired over the 23 year period from 1977 to 2000. Given the national average heating-energy-use level which we estimated for 2000, some 75.72 million Btu's per unit for previously existing structures, these retirements would result in the reduction of total net residential energy use by 0.61 quads in 2000. (This decrease would be partially balanced by the replacement of the retired units with more effi-

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1/E. B. Wilson, Jr., An Introduction to Scientific Research, McGraw-Hill, New York, 1952, pp. 272 to 274.

cient new units with an average energy consumption of 44.53 million Btu's per unit, using a total of 0.36 quads in 2000. Thus the resulting reduction of total net residential energy use due to retirements would be 0.61 - 0.36 = 0.25 quads, or 2.2 percent of the total.)

The assumption that retired units will have the same heating energy efficiency as the overall average for the pre-1977 stock will not likely be exactly correct, so we need to estimate the uncertainty due to the assumption. On one side, it is possible that there will be some tendency to retire less efficient units, rather than average ones, which would lower total energy use; on the other side, some retirements could come from newer, more efficient units, because of other development projects which take the land on which they were built. This estimation can only be very rough, because we could not find data on the heating efficiency or age composition of retired structures.

At one extreme, we would suggest that preferential retirement might involve as much as one-third of the units retired, with those units averaging energy consumption one quarter again as high as the value computed for the overall average of the existing stock. This would mean that the reduction in energy use due to retirements would be greater by the product of (8.05/3) million units x (75.72/4) million Btu's per unit, for a total of 0.06 quads, which is about one-half percent of total estimated net residential energy consumption.

At the other extreme, we would suggest that, at most, about one-quarter of the retirements might be of units built subsequent to 1977, the replacement of which would be by units of the same efficiency. In that event, the reduction in residential energy use due to retirements would be lessened by one quarter, or some 0.06 quads--about the same one-half percent of total consumption.

While these two effects may quite likely cancel each other in part, we will leave this uncertainty term at $\pm$0.5 percent.

Test calculation--mix of housing types

It is known, from studies of the present housing stock, that different types of structures use different amounts of heating energy. These differences will mean that the contribution to estimated energy consumption by new housing units will be affected by the mix of housing types built.

Given the same average space per unit, single-family detached houses use the largest amount of heat because they have the largest proportion of outside surface through which to lose heat. In the BEPS analysis, single-family attached houses show design energy budgets about 15 to 30 percent lower than detached ones. The multi-family building energy budgets in the BEPS analysis are not directly comparable to single-family house

budgets, because the multi-family building budgets include the energy consumption of a number of common building services. However, other studies have shown that heating energy consumption by multi-family units is well below that for single-family ones, which is consistent with the multi-family units having much smaller surfaces exposed to the outside, through which to lose heat, in addition to their generally being smaller. Finally, the BEPS analysis was not able to set standards for mobile homes, but previous work suggests that, at present, their heating energy consumption falls between that of single-family and multi-family structures.

Our treatment of heating energy use in new structures was based on the calculated heat requirements of 1,600-square-foot, single-family houses. This is about the median size of new single-family houses that have been built in the last several years. Recent construction data suggests that a trend of the 1960s and early 1970s, toward larger sizes in new houses, had halted in the middle 1970s; therefore, we have maintained this size through the balance of the century. We suspect that economic pressures and rapidly rising construction costs, as well as smaller numbers of persons per household in the future, are likely to work against a renewed growth in house sizes for the next 2 decades.

The assumption of describing the heating energy requirements of all new housing units by the value calculated for the single-family detached units may well lead to some overestimate of this demand. The extent of the overestimate would depend on the proportions of the new housing stock which are made up of detached vs. attached or multi-family units. To estimate this effect, we can compare the calculated consumption for new units in two different mixes which we believe are very likely to span the range in which the actual mix will fall. Taking attached and mobile units as averaging 80 percent of the heating energy use of detached ones, and multi-family units as averaging 60 percent of that level, we find that a mix which was 60 percent detached and 20 percent each of the other two classes would have an energy consumption level 12 percent lower than that computed for the all-detached stock. At the other extreme, a mix which was only one-third detached and one-third each of the other two classes would have an energy consumption level 20 percent lower than that computed. This change, however, would apply only to the newly constructed part of the housing stock, which is calculated to have lower heating energy requirements than existing units, so that its effect on total residential consumption would be proportionately smaller. In fact, the range of housing mixes which we have examined here would reduce our estimated total residential net energy consumption in 2000 by between 1.5 and 2.5 percent, so that effects of shifts in the mix are themselves likely to be contained within a range of only ±0.5 percent. The overestimate introduced, by computing heating demands as if the entire stock were single-family detached units, amounts to 2.0 ± 0.5 percent of the national total in 2000.

Rather than making this change in our projection, however, we have left the total stand, because we tentatively judge that the overestimate it introduces will approximately balance the underestimate that may arise from the uncertainty of success in actual thermal performance of houses matching the BEPS levels. (See p. 33.)

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